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Maritime Meteorological Summary of western North Pacific Ocean in Winter

By

Shigeaki HAYASHI, Ikihiko MIYASHITA and Igoro FUJITA

Japan Meteorological Agency

(Received November 25, 1968)

Abstract: The characteristic weather of the western North Pacific could be summarized as an alternation between the passage of migratory temperate front in the subtropical region and seasonal advances and retreats of the Intertropical Convergence Zone.

In winter in the western North Pacific there are outbreaks of more or less modified Polar air. The cold Asiatic anticyclonic cell has become stronger and the North rarely extends to the tropics. At the same time, the North Pacific Trades prevail in this waters and become mE air at the Equator. The Intertropical Convergence Zone of the Northern Hemisphere retreats to the Southern Hemisphere due to the invasion of North Pacific Trades crossing the Equator.

However, the waters observed are the space areas owing to scantiness of weather stations. Individual factors on surface temperature, dew point temperature and sea surface temperature make it possible to study meteorological features along 137°E from the south coast of Japan to New Guinea in January to March 1967 and 1968 on board R/V Ryofu Maru. The adiabatic chart was made so as to find out the relation of the air mass and the ocean current. In addition, the general weather tendencies of each month are investigated. Further examination is necessary for more detailed measurements of radiation from the sky and sea.

1. Introduction

Meteorological observations of the Cooperative Study of the Kuroshio and Adjacent Regions (CSK) were carried out both for the maritime meteorological and oceanographic studies.

Routine surface observations were carried out 8 times a day, namely, 00, 03, 06, 09, 12, 15, 18, and 21 GMT, respectively. Such obtained data were sent to J. M. A. (Japan Meteorological Agency) and to coastal radio stations along the

coast of the western North Pacific Ocean immediately after the observations.

Sometimes special observations, such as three dimensional wind measurements with ultra-sonic anemograph along the longitudes 137°E , $133^{\circ}30'\text{E}$, 130°E and 127°E were carried out only on the southward leg.

2. Wind systems

In these regions (western North Pacific), the main features of wind system may be summarized as follows: Northers, North Pacific Trades, the Westerlies, Asiatic Monsoon, South Pacific Trades and South Indian Ocean Monsoon. Under the classification, Northers are categorized as all modified cP or mP air mass which is originated from the interior of northern Asia and reaches the tropical and equatorial western Pacific after travelling over one of the three typical routes indicated in the next place. Namely, (1) a north-southeastward route across China which ends in the South China Sea west of the Philippines, (2) a west-eastward route across China—the air mass leaves the continent south of the Yellow Sea, then gradually veers southward, and (3) a north-southward route off the east shore of Asia—the air mass passes over water from the Okhotsk Sea continuing its journey to southward (MAURICE, 1947).

While advancing across the tropical area, the air mass is thoroughly modified due to the absorption of higher heat and moisture from the sea surface. When it occasionally penetrates into the Southern Hemisphere, it may be resembled to an eM air mass, under the influence of the left-hand deflecting Corioli's force of the Southern Hemisphere. The air mass then appears as a northwesterly monsoon. The general designation of "Westerly" is applied to the Westerlies overlying the trades, and to their northern continuation, the surface westerly of the middle latitudes. The Asiatic Monsoon is a subsident air mass having northeasterly flow along the east side of the Asiatic dynamic anticyclonic cell. It crosses the Equator and is soon reduced to westerly wind in the south side of the Equator (MAURICE, 1947). The North Pacific Trades are the subsident mT air mass from the North Pacific anticyclonic cell, and are usually called the Northeast Trades. Naturally stable, this subsident air mass is only modified by strong convergence, such as that occurring when it extends to the Southern Hemisphere as a deflected northwesterly or westerly monsoon wind.

The South Indian Ocean Monsoon is a subsident air mass, originally a southwesterly flow along the east side of the South Indian Anticyclone. It becomes

a convergent westerly monsoon crossing the Equator and enters into the Northern Hemisphere.

On the other hand, the South Pacific Trades are mTs air mass which is originated from the South Pacific anticyclonic cell. Their characteristics are quite similar to those of the North Pacific Trades. Entering the Northern Hemisphere, it appears as a southeasterly monsoon with mE air mass trades.

The monsoon season starts from late autumn because of the outbreak of the Siberian anticyclonic cell. According to the analysis of the data obtained in January 1967 and 1968 along longitude 137°E (Figure 1), it is a subsident air mass fastened in the northeasterly flow along the east side of the Asiatic anticyclonic cell. In the area from the south coast of Japan to latitude 34°N, wind direction is westerly or northwesterly, with its speed amounts of 10-20 knots. In 1968, these anticyclonic cells invaded far southward and there were the northwesterly of 20-35 knots in latitude 27°N. In the area from latitude 27°N to about 8°N, there existed the North Pacific Trades belts, where excellent northeasterly or easterly having a speed of 20 knots or more predominated. In 1968, the wind intensities were weakened compared with 1967. In addition, in the area from latitude 7°N to near the Equator, where the Equatorial Counter-current flowed, both of the North Pacific Ocean Trades and the South Indian Ocean Trades were blowing and so there existed weak wind speed zone having unstable wind directions. In winter, usually, while the North Pacific Trades predominate, northeasterly wind crosses the Equator as

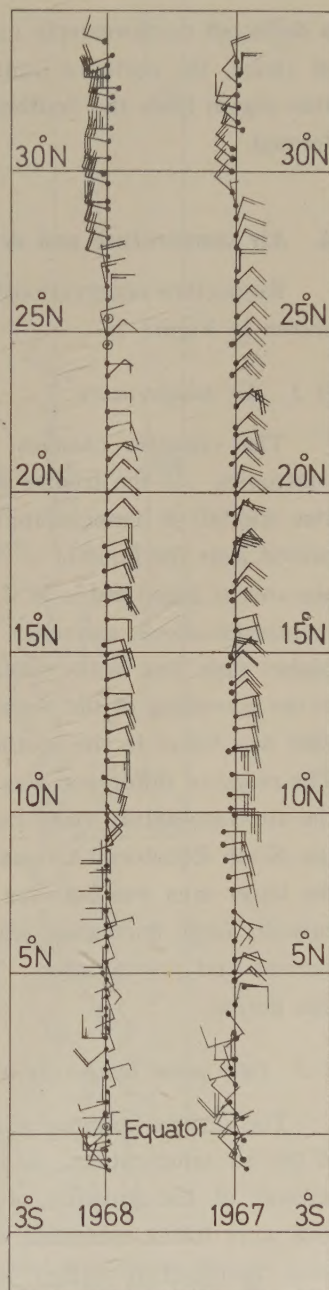


Fig. 1. The distributions of wind direction and wind speed along longitude 137°E in January 1967 and 1968.

a deflected northwesterly monsoon wind in the Southern Hemisphere. However, at times, the northern limit of the Intertropical Convergence Line is shifted in this region from the Southern Hemisphere, and a weak tropical depression is formed.

3. Air temperature and dew point and sea surface temperatures

Respective observational data along the longitude 137°E in two years are shown in Figure 2.

3-1 Air temperature

The climatic changes which are definite and regular are found in the subtropics. In the tropics seasonal variation becomes less clear-cut and a simple rise and fall of temperature by the variation of the sun altitude are not to be expected near the Equator. The mean annual temperature is 16°C in the southern sea area of Japan and is 26°C in the tropics (HERBERT, 1954). According to the fact mentioned above, generally, in winter, the air temperature in the tropics is higher than that in the subtropics by the large land masses in the north. Owing to the spreading of the Asiatic dynamic anticyclonic cell, the air temperature in 1968 was lower in the southern sea area of Japan than that in 1967 in this period. The range of difference was about 5°C. In the area from latitude 30°N to 20°N the air temperature rised rapidly but from latitude 20°N to near 7°N, a zone of the North Equatorial Current, the temperature was almost stable. Its range in the latter area was between 23°C and about 27°C. Over the Equatorial Counter-current, large fluctuation was seen because of the influences of the wind, ocean current and precipitation. The maximum temperature reached 29°C or more in this period.

3-2 Dew point temperature

The various features of dew point temperature were almost similar to those of the air temperature. In the southern sea area of Japan the value is low on account of the growing of the Asiatic cP air mass. Especially, the values in 1968 were lower compared with those in 1967. The air temperature and dew point temperature reflect the characteristics of the participating respective air mass. Namely, in the area from south coast of Japan to approximately latitude 20°N, these values clearly pointed out the invasion of the Asiatic continental air

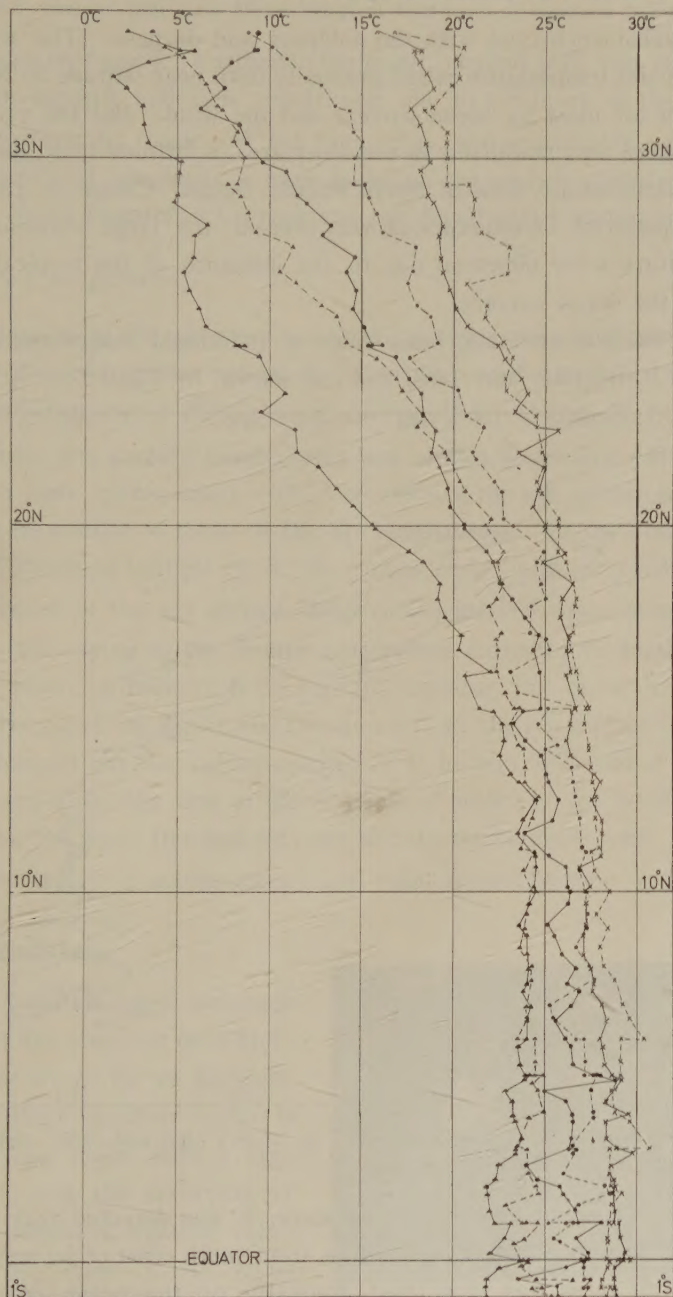


Fig. 2. The distributions of air temperature, dew point temperature and sea surface temperature along longitude 137°E in January 1967 and 1968. ●: Air temperature in °C, ▲: dew point temperature in °C, ×: sea surface temperature in °C. Broken line: 1967, Solid line: 1968.

mass having subsidence type with the coldness and dryness. The air temperature and dew point temperature raised gradually until near latitude 20°N due to the modification of air mass by ocean current and the wind. But the value of dew point temperature was stabilized in the south area of latitude 15°N , because there existed the maritime air mass of North Pacific Ocean. Closer to the Equator, where the Equatorial Countercurrent was present, the large variations of dew point temperature were observed due to the influence of the tropical maritime air mass and the ocean current.

We made the wet adiabatic lapse rates of individual observations along the longitude 137°E in 1967 and 1968, and are shown in Figure 3. According to

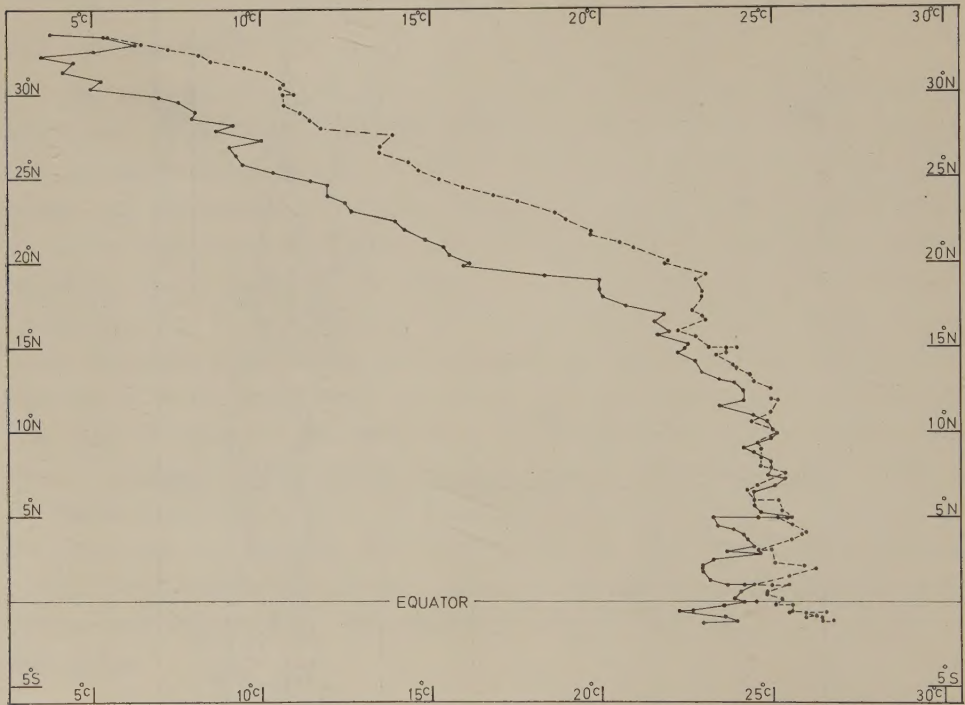


Fig. 3. Wet adiabat along longitude 137°E in January 1967 and 1968. Solid line: 1968, Broken line: 1967.

analysis of this wet-bulb potential temperature, it was detected that the Asiatic continental air mass dominated in the area from south coast of Japan to latitude 17°N and this air mass was modulated gradually by the ocean currents. The range varies from 5°C to 23°C . In the area from latitude 17°N to near 5°N the wet-bulb potential temperature, being around 25°C , showed same value and

tendency between two years. Further to the south, beyond 5°N , the variations of each year were opposite and were remarkable due to existence of the flow from the tropical maritime air mass. At the same time, the remarkable variations of the wet-bulb potential temperature were found on the each border between the Kuroshio, the North Equatorial Current and the Equatorial Countercurrent.

3-3 Sea surface temperature

The distributions of sea surface temperature in two years are shown in Figure 2. Usually, in the tropics the values of the sea surface temperature were below 30°C , having a maximum of daily temperature at about 15 o'clock Local Time, and at other times, sea surface temperature was almost stationary. Daily ranges of temperature were rather small. The variations of the sea surface temperature in two years were similar to those of the air temperature. In the area from the south coast of Japan to latitude 25°N , the values rised with proceeding to the south. The ranges of the sea surface temperature in 1968 were lower compared with those in 1967 owing to the Asiatic anticyclone extended to southward. In the area from about latitude 17°N to near the Equator, the belts of the North Equatorial Current and the Equatorial Countercurrent, the sea surface temperature remained unchanged but the values reached 30°C in near 6°N and 3°N . These phenomena were probably due to the invasion of water of the Southern Indian Ocean from the Southern Hemisphere; sea surface temperature rised, wind direction became southerly or southwesterly and wind speeds became weak.

4. General remarks

While we were on board, we made surface stream line charts at 00 G.M.T. usually once a day as far as possible. The Ryofu Maru's weather radar is designed for long range with a high power out put, and the receiving of echo by this powerful weather radar was carried out once a day at 00 G.M.T. Results of these observations are shown in Figure 4. According to the analysis of these observations for

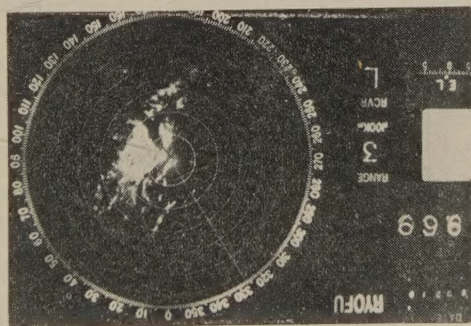


Fig. 4. The PPI echo picture showing the passage of cold front (February 19, 1968). The position is latitude $21^{\circ}00'\text{N}$ and longitude $129^{\circ}49'\text{E}$.

the data in 1967 and 1968, it is definite that tropical regions of the Pacific are subject to considerable seasonal variation. Through the Pacific, the equatorial regions are greatly influenced by the intertropical front and the troughs in the summer Hemisphere. The subtropical regions of the western North Pacific, however, are less affected. Now, let us describe typical oceanic cases extending into both hemispheres after month to month.

4-1 January

The trades are warmer than the Northerners in the area north of Manila. The mTs air mass of lower latitudes is considerably moistened and unstabilized, and becomes eM air mass at the Equator. The Typical weather in modified Polar air at the west area of temperate front is represented by the abundance of Cirrus, Cirrostratus and Altocumulus, and by dark Stratocumulus sky with showers. The typical weather in mT air at the east area of temperate front is shown by little cloudness with some Cumulus and Stratocumulus. Wind direction is southeasterly or southwesterly (Figure 6).

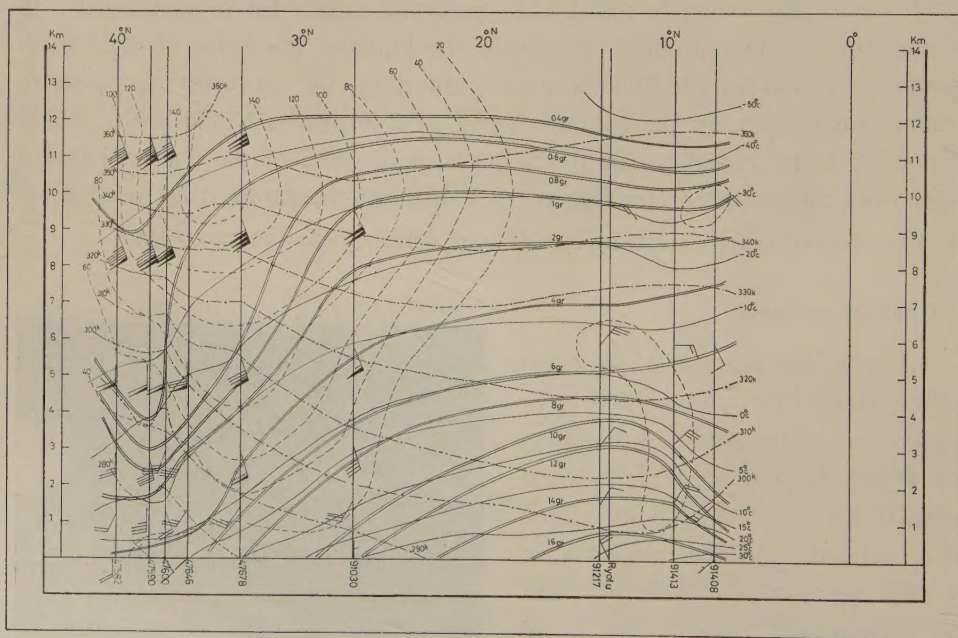


Fig. 5. Vertical cross section along longitude 140°E in January 20, 1968. Solid line: Air temperature in °C, Broken line: Wind speeds in knots, Dotted line: Equivalent potential temperature in °K, Double solid line: Mixing ratio in gram.

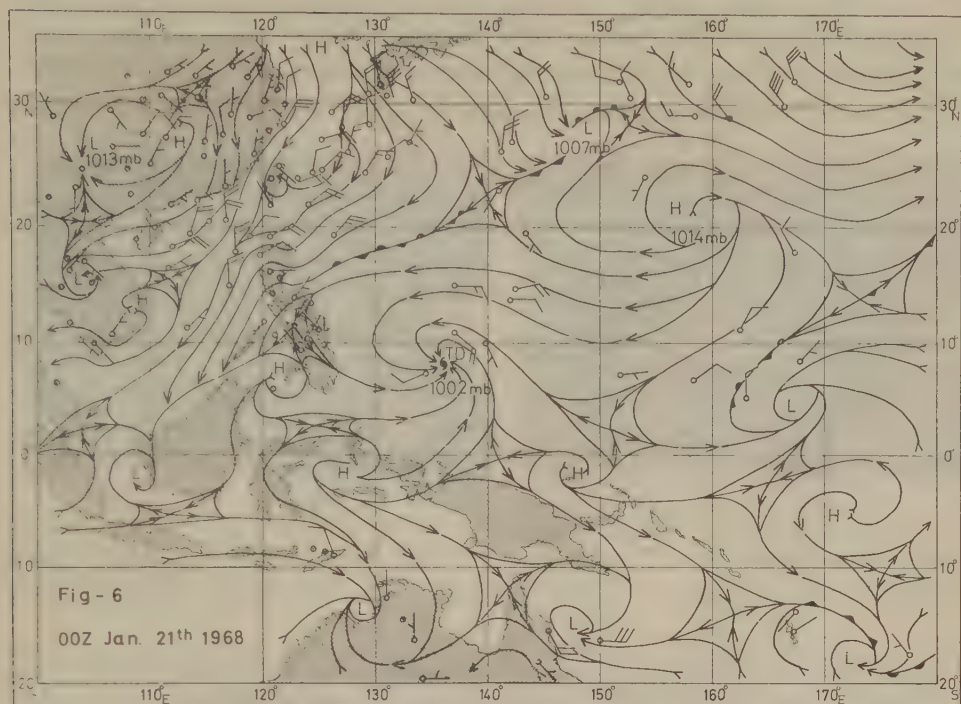


Fig. 6. Stream line at the surface. 00Z. January 21, 1968.

When the temperate front is located near the Asiatic coast, and oscillates between the southwest coast of China and the northern Philippines, a northern branch of the North Pacific Trades is well developed. The temperate frontal circulation off the coast of China is much influenced by the above-mentioned facts. On the hand, a southern branch is deflected into the Southern Hemisphere as northwesterly or westerly wind, and this flow is diverted to the east by the Australian thermal low (U. S. Navy, 1956). Between Sumatra Island and Australia the surface flow along the southern limit of the Intertropical Convergence Line is usually westerly. The intertropical disturbances occur rarely in the north of nearly latitude 5°N . Commonly they are accompanied by an eastward flow of Asiatic monsoon, and then the tropical depression is drifted well to the west if the North Pacific Trades are sufficiently strong. In addition, the Westerlies dominate farther to the north, beyond latitude 20°N , at about 1.5 Km (Figure 5).

4-2 February

There was not so much changes of the wind system from January to-

February except the weakened Northers at the surface. The temperate front did not pass the Mindano. The frontal situation was similar to that in January. The temperate front lay ordinarily through Thailand and between Luzon and



Fig. 7. The echos showing a large Cumulus (February 6, 1968). The position of ship is latitude $07^{\circ}30'N$ and longitude $126^{\circ}45'E$.

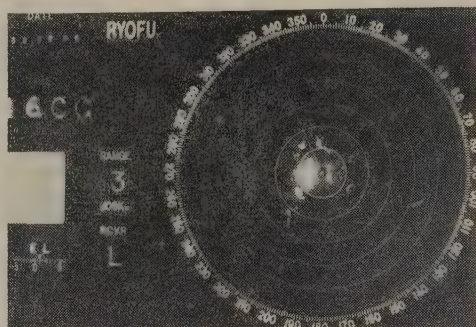


Fig. 8. The radar echos showing the top of Cumulus congestus and Cumulonimbus capillatus. The height of top of each cloud is about 5,000 meters to 13,000 meters. These clouds are moving westward.

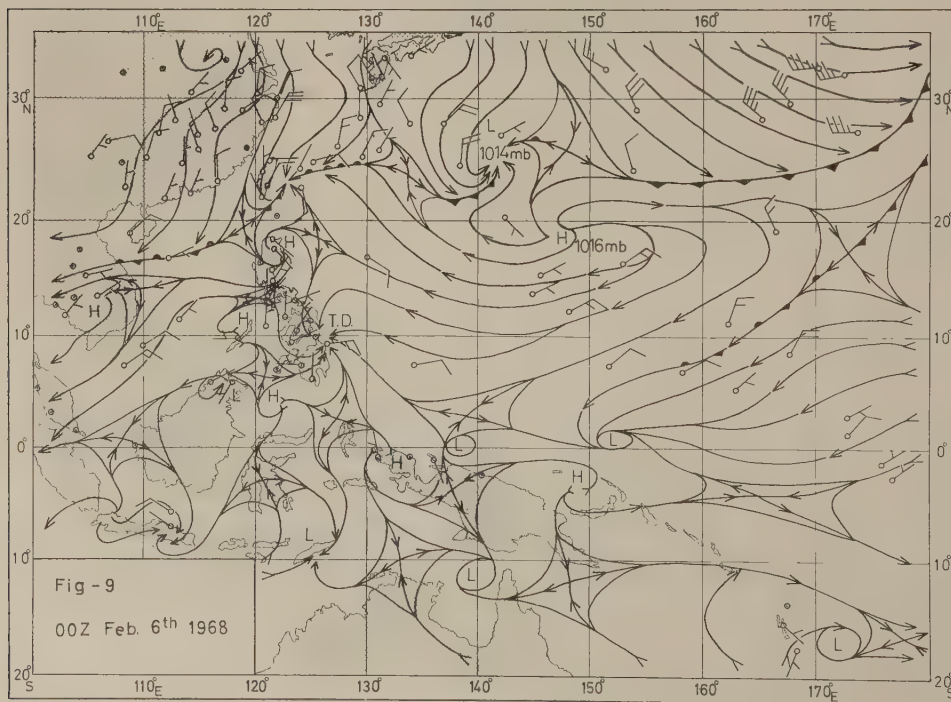


Fig. 9. Stream line at the surface. 00Z. February 29, 1968.

Taiwan, instead of passing through the southern Philippines.

The southeasterly wind which is a northern branch of the North Pacific Trades gains in strength at the surface and extends farther west toward Thailand. The Westerlies are limited to the south of Burma and between Thailand and Luzon (Figure 9). The tropical depression and typhoon in this month occurred rarely under exceptional circumstance, being similar to those in January, because the northern limit of the Intertropical Convergence Line extended from the Southern Hemisphere to near latitude 5°N , where the boundaries between the North Equatorial Current and the Equatorial Countercurrent existed. At the same time, cyclogenetic shear of the North Pacific developed well by the mT air mass and the convergence in the tropics was supplied from the Southern Hemisphere by the deflected Southern Indian Monsoon of which the wind direction was westerly or southwesterly. On the other hand, a temperate front of the North Pacific provides the conditions necessary for the formation of the tropical depression. The more typical weather of the equatorial trades is characterized by the large amounts of Cumulus and Cumulonimbus clouds, and

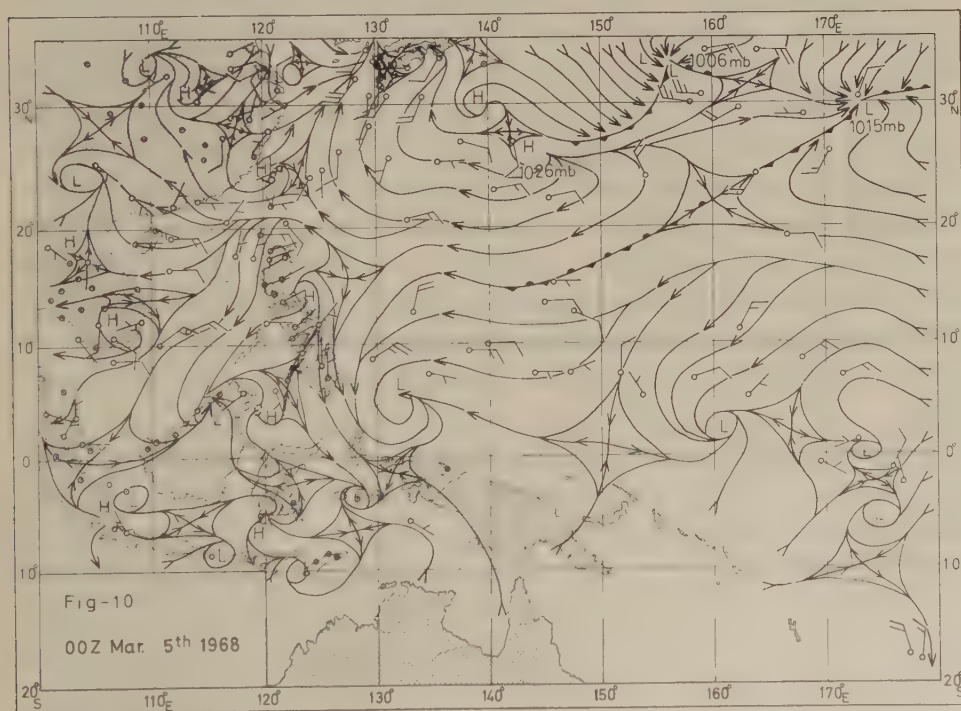


Fig. 10. Stream line at the surface. 00Z. March 5, 1968.

the abundant and widely distributed chaotic Cirrus. Such weather continues to the farther north (near the north of the Philippines). According to the observation of the weather radar in the tropics, there is a band of frontal cumuliform type clouds with moderate or heavy showery precipitation and at times featured thunderstorms. The ceilings above the sea surface are generally about 600 meters with tops exceeding 7,000-8,000 meters. Copies of these radar observations are shown in Figures 7 and 8.

4-3 March

The Asiatic cold anticyclone weakens on the continent. The North Pacific Trades which are replaced by the Northerners in the South China Sea extend to the south of the Equator. In the area between the International Date Line and near longitude 110°E, the trades crossed the Equator, continuing as a northwesterly trades to approximately latitude 10°S. Also this northwesterly trades flew past through Timor and flew into the Australian thermal low (U. S. Navy, 1956). The North Pacific Trades between the Philippines and Malay remained at approximately latitude 10°N, with some trades deflected into the Southern Hemisphere. However, in the north, a part of the trades deviated into the temperate front zone through the northern coasts of the South China Sea. The situation of Intertropical Convergence Zone in the areas of Borneo and Celebes was exceedingly complicated because of the invasion of the North Pacific Trades into the Southern Hemisphere, and also of the extension of the South Indian Ocean Monsoon as a westerly wind in this area at the surface. The first tongues of the South Indian Ocean Monsoon and the South Pacific Trades extend to the Northern Hemisphere as far as the southern tip of the Philippines. If they reach farther east (near the Caroline Islands), the tropical depression may occur in the region.

Occasionally, the waves are formed in the area west and east of the Philippines, while if the temperate front developed well in the region of the north Philippines, the small and weak fluctuation occurred in the area of north Taiwan and it developed into a low. The stream line chart at the surface of March is shown in Figure 10.

4-4 Tropical depression and typhoon

The tropical depression and typhoon in winter in the Northern Hemisphere:

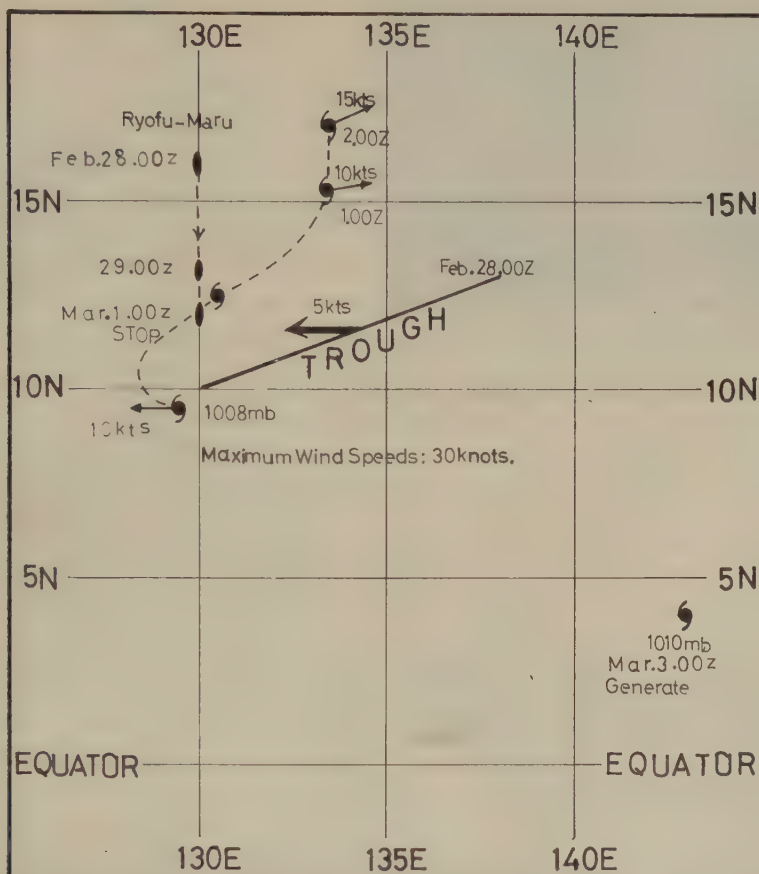


Fig. 11. The route of tropical depression and course of Ryofu Maru.

occur rarely under the exceptional circumstances. According to the observation on February 28, 1968, the tropical depression generated in latitude 9.5°N and longitude 129.5°E , having pressure of 1,000 mb and the maximum wind speed of 30 knots. She moved westerward by 10 knots, based on the circulation formed by the North Pacific Trades which flow along the stationary front of the sub-tropical low and the Intertropical Convergence Line which was deflected in this waters through the Equator from the Southern Hemisphere by the South Indian Trades. On 29th, she recurved near latitude 10°N and moved to northeast by 12 knots. On March 3rd, she weakened gradually and became the subtropical low. These are shown in Figures 11, 12, 13 and 14.

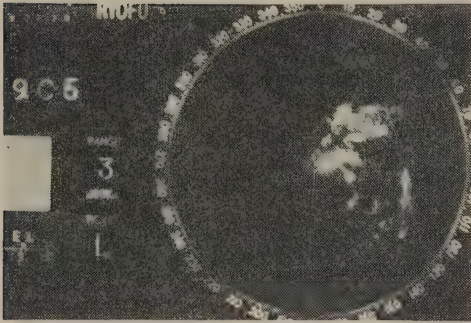


Fig. 12. Tropical depression (February 29, 1968). The position of ship is latitude $13^{\circ}01'N$ and longitude $130^{\circ}01'E$.

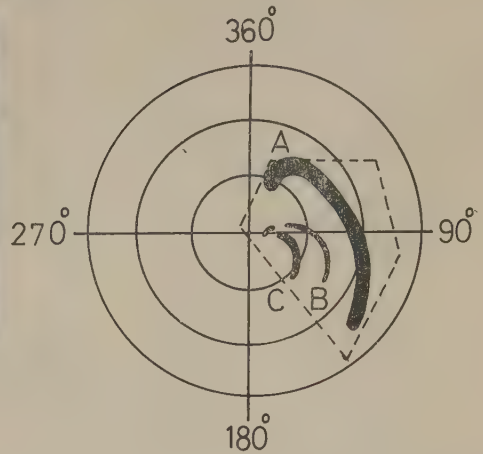


Fig. 13. Analysis of tropical depression by radar. (00Z, February 29, 1968). Position: latitude $13^{\circ}01'N$, longitude $130^{\circ}01'E$, (A): Spiral echo, Mdt. Cu, Nc., Wed. 20 Km, Top 9,000 meters, (B): Spiral echo, Mdt. Cu, Nc., Top 11,000 meters, (C): Spiral echo, Wk. Cu, Inc., Wed. 10 Km. Top 6,000 meters, Broken line: Wk. Nc.

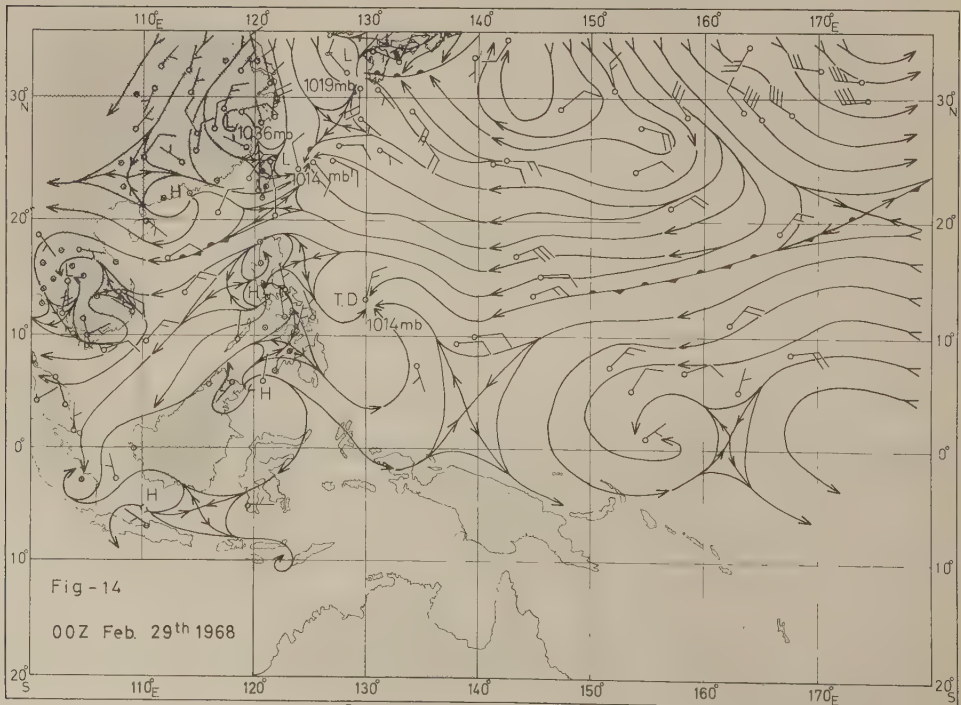


Fig. 14. Stream line at the surface. 00Z. February 29, 1968.

4-5 Intertropical Convergence Zone

Usually, the Intertropical Convergence Zone exists between latitude 10°N and 10°S and extends east and west. The breadth of the Zone is wide (commonly 500-1,000 Km) and becomes occasionally a line. No same situation of convergence exists in the Intertropical Convergence Zone but the air diverges in some place. It may be said that the equatorial air mass overspreads and the equatorial high pressure belt or equatorial low pressure belt exists in this Zone. Speaking from a general view, the Intertropical Convergence Zone migrates towards the Southern Hemisphere crossing the Equator due to the seasonal changes which are the elevation of sun altitude, the extension of developed subtropical anticyclone and moreover the North Pacific Trades as northeasterly wind blown toward the Equator in late autumn or in early winter (NEMOTO *et al.*, 1966).

According to the analysis of stream line charts and observational results in 1967 and 1968, the portion of the Intertropical Convergence Zone in the Southern Hemisphere was more clearly distinguished. The southern limit of the Zone existed along near latitude 10°S , but the northern limit was indistinguishable. The respective trades of both hemispheres converge into the Zone but these trades have almost the similar character due to the flow crossed over the warmer waters. Moreover, the equatorial high pressure belt in the Zone has a same character, too. Therefore, the results of observations in two years could not detected exactly the Intertropical Convergence Zone by air temperature and dew point temperature (Figure 3). Its northern limit is almost indistinguishable over the waters north of New Guinea as former expansion but it may be located in Sumatra Peninsula, North Borneo and the South China Sea.

According to the observations for two years, some features of the Intertropical Convergence Zone are as follows:

(a) There is wind shift line, but occasionally wind direction varies in both the northern and the southern limits.

(b) The limits of Intertropical Convergence Zone have not the character as a definite warm front or marked cold front, and have not the wave which is to be compared with the Polar front or temperate front waves, because in the tropics a front such as a warm or cold front in the subtropics disappears.

In tropics, it occurs a updraft and downdraft. In the Zone of updraft Cumulonimbus develops well. Near the both limits of the Zone which are active, the weather is characterized by long row of heavy Cumulonimbus with drawn-out

Cirrus and Cirrostratus screens at their tops, with Altocumulus at their midway, and with squall or thunderstorm.

(c) In the area of Intertropical Convergence Zone, squalls are observed everywhere. Squalls are characterized by sudden commencement, rapid development and disappearance. Sometimes whole sky is covered by squalls for long time.

(d) The results of observations detect that air temperature falls rapidly with the commencement of squall and lower temperature prevails over the neighboring waters.

(e) As stated above, the Intertropical Convergence Zone is existing in the Southern Hemisphere in winter. It extends rarely to the northern waters of the Equator, while the northern limit of the Intertropical Convergence Line remains where the border between the North Equatorial Current and Equatorial Counter-current exist. The weakened turbulence may be induced probably due to the well-developed shear of the subtropical low and the trough of the Westerlies in upper air.

Acknowledgments: The authors wish to express their gratitude Dr. H. FUTU, former Chief of Marine Division, to Dr. I. IMAI, Chief of Marine Division, to Mr. S. KAWAMURA, Chief of Maritime Meteorological Section, to Dr. J. MASUZAWA, Chief scientist of this survey and to Dr. M. HANZAWA and Mr. Y. KUGA, Marine Division, Japan Meteorological Agency for their consistent interest and guidance in making this report. All members of the officers and the crews of the Ryofu Maru for their aid throughout this investigation, are also acknowledged.

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On the Anomaly of the Sea Surface Temperature in the East China Sea (II)

By

Shigeo MORIYASU

Meteorological Research Institute

(Received December 5, 1968)

Abstract: Spectral analyses are made on the anomaly of mean sea surface temperature in the East China Sea. Three cases are taken, that is, ten-day anomalies in 1° quadrangle of longitude and latitude, and monthly anomalies in 1° quadrangle and 2° quadrangle. The comparison of the results of spectral analysis shows no significant differences, and common characteristic features are obtained in each case. Based on ten-day anomalies in 1° quadrangle, the transmission of the anomaly is discussed for the Kuroshio region and the coastal water region.

1. Introduction

In the previous report (MORIYASU, 1967), spectral analysis was made on the anomaly of ten-day mean sea surface temperature in 2° quadrangle of longitude and latitude. It is interesting to see how the results are changed by the scales of time and area. For this purpose, the analysis is made for various scales of time and area in this report. As the scale of area, 1° quadrangle (I) and 2° quadrangle (II) are taken (Fig. 1). As the scale of time, a ten-day (T) and a month (M) are taken. Therefore, there are four cases as the combination of the scales as follows:

Case II-T ten-day anomalies in 2° quadrangle

Case II-M monthly anomalies in 2° quadrangle

Case I-T ten-day anomalies in 1° quadrangle

Case I-M monthly anomalies in 1° quadrangle.

Case II-T was discussed in the previous report. Though the area is smaller in the latter two cases, there is no difference in the mean values between Area 1 of Case II-T and Area 1 of Case I-T and between Area 1 of Case II-M and Area 1 of Case I-M, because the points included in the area are quite the same.

It was discussed in the previous report how ten-day anomalies in 2° quadrangle

are transmitted in the Kuroshio region and the coastal water region. The results are not satisfactory and the problem is studied based on ten-day anomalies in 1° quadrangle to remove unessential effects.

2. Data and method

The data are those used in the previous report, that is, ten-day mean values at 140 points from 1954 to 1962 (Nagasaki Marine Observatory, 1964). The monthly mean value is the arithmetic mean of three ten-day means in the month. The spectral analysis is made by using the method used in the previous report (BLACKMAN and TUKEY, 1958). In the analysis of monthly anomalies, the number of samples (n) and the number of the greatest lag (m) are 108 and 12, respectively, and the number of degrees of freedom (ν) is approximately 18. The time interval is $1/12$ year and the frequency (f_r) is given by $r/2$ cpy, where r is integer from 0 to 12. In the analysis of ten-day anomalies, n is 324, m 36, ν approximately 18, f_r $r/2$ cpy (r is integer from 0 to 36). Thus, the both analyses have the same resolution, but frequency bands higher than 6 cpy are rejected in the analysis of monthly anomalies. Twenty 2° quadrangles are taken in Cases II-T and II-M. Areas 1 and 13 are assumed to be the source of the Kuroshio

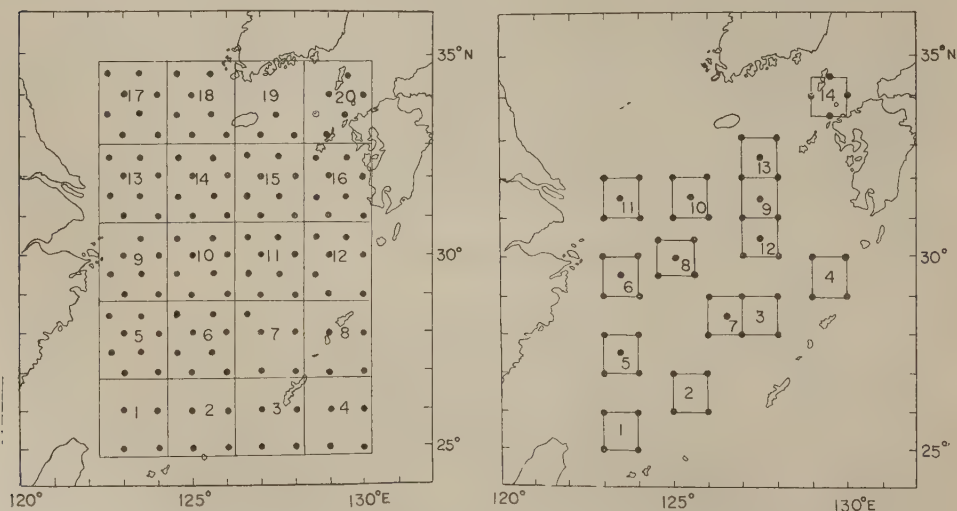


Fig. 1. Location of area and of points for which the ten-day mean sea surface temperature is given. Numerals indicate the area number.

left Cases II-T and II-M
right Cases I-T and I-M

water and the coastal water, respectively (Fig. 1). Fourteen 1 quadrangles are taken in Cases I-T and I-M. Areas 1 to 4 and Areas 12 to 14 are located in the Kuroshio and the Tsushima Current region, respectively, while Areas 5 to 10 are distributed at approximately equal distance in three directions from Area 11, which is assumed to be the source of the coastal water (Fig. 1). The selection of areas is to see the effects of advection and of diffusion in each region.

3. Comparison of variance and spectrum for various scales

It is expected that the variance is greater for smaller scale of time. Table 1 shows variances of some areas. Area 1 of Case II, Area 12 of Case II and

Table 1. Variances in (°C)².

Case	Area	Variance	Case	Area	Variance
II-T	1	0.3670	II-M	1	0.2307
II-T	13	1.0318	II-M	13	0.7204
I-T	11	1.0742	I-M	11	0.7540
II-T	12	0.3998	II-M	12	0.2603
I-T	4	0.3969	I-M	4	0.2578

Area 4 of Case I are located in the Kuroshio region and Area 13 of Case II and Area 11 of Case I are located in the coastal water region. Variances of monthly anomalies are about 0.65 and 0.70 times variances of ten-day anomalies in the Kuroshio region and the coastal water region, respectively. Thus, there is little difference in the ratio of variances between the two regions.

Table 1 also makes it possible to compare variances between two scales of area. Area 11 of Case I is a portion of Area 13 of Case II and Area 4 of Case I is a portion of Area 12 of Case II. The variance is a little greater at Area 11 of Case I than at Area 13 of Case II, while there is no difference in the variance between Area 12 of Case II and Area 4 of Case I. It is inferred that such a difference in scale of area is not important in the computation of variance.

Nyquist frequencies are 18 cpy and 6 cpy for ten-day anomalies and monthly anomalies, respectively, and it is impossible to compare spectral densities for frequency bands higher than 6 cpy. The comparison of spectral densities is made for Area 1 and Area 13 of Case II (Fig. 2). Common features are found in the change of spectral density with frequency for tenday anomalies and for monthly anomalies and the value is nearly the same. Thus, it is not the point

for the discussion on the variation of the lower frequency whether ten-day anomalies are taken. This is valid for other areas, too.

Influence of the scale of area on spectral densities of ten-day anomalies and of monthly anomalies is not marked (Fig. 3). This means that the scale of the phenomenon is larger or equal to 2° in latitude in the example. But, the influence is expected to be marked where variations of smaller scale are predominant.

As stated above, characteristic features of variances and of spectral densities for Cases II-M, I-T and I-M are nearly the same as those for Case II-T discussed in the previous report. Variances are greater and most of the power is concentrated in the low frequency bands for the northwestern part. Figs. 4 and 5 show average persistence (RODEN, 1962) and variance for Case II-M.

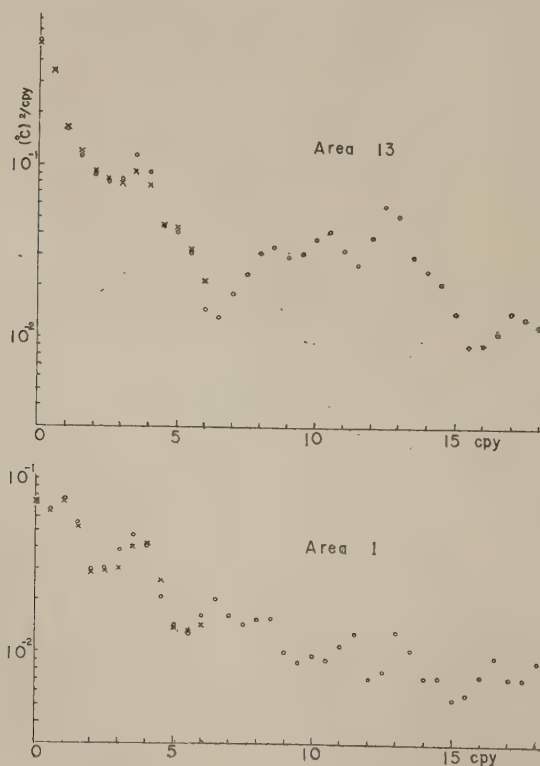


Fig. 2. Comparison of spectral densities.
 × Case II-M, O Case II-T.

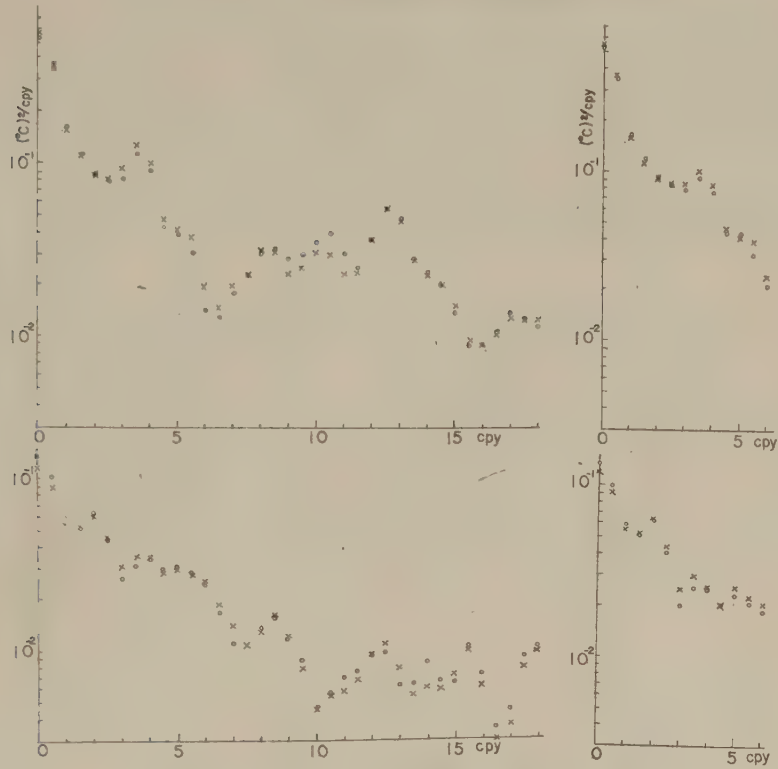


Fig. 3. Comparison of spectral densities of ten-day anomalies (left) and monthly anomalies (right).

upper { × Area 11 of Case I lower × Area 4 of Case I
 ○ Area 13 of Case II ○ Area 12 of Case II

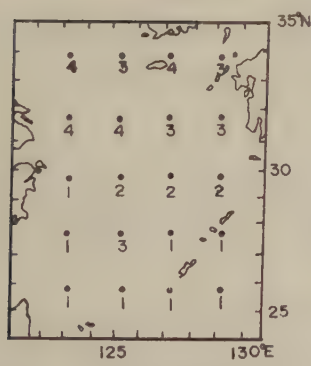


Fig. 4. Average persistence in months for Case II-M.

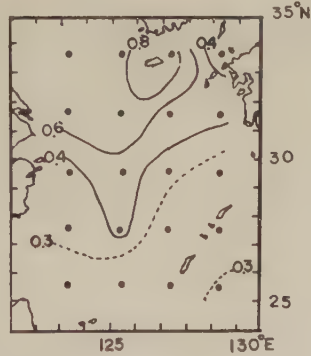


Fig. 5. Variance in (°C)² for Case II-M.

4. Crosscorrelation and coherence for Case II-M

The crosscorrelation coefficient is computed between Area 1 and other areas and between Area 13 and other areas (Figs. 6 and 7). The value decreases

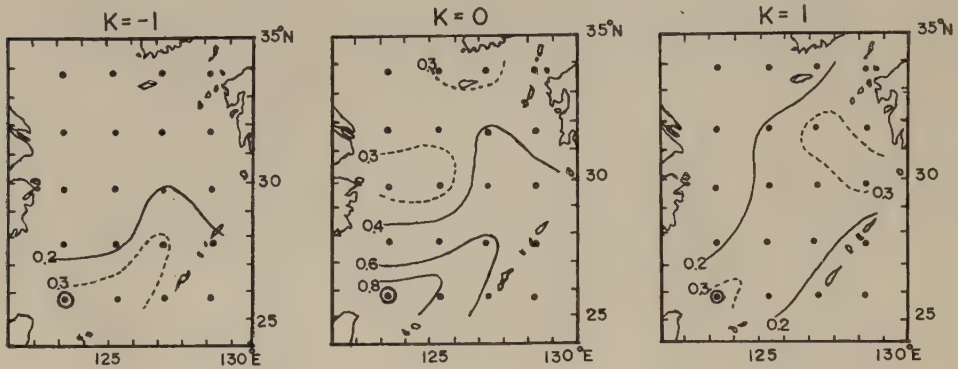


Fig. 6. Crosscorrelation coefficient for Case II-M. Reference area is Area 1.
 k is number of lag.

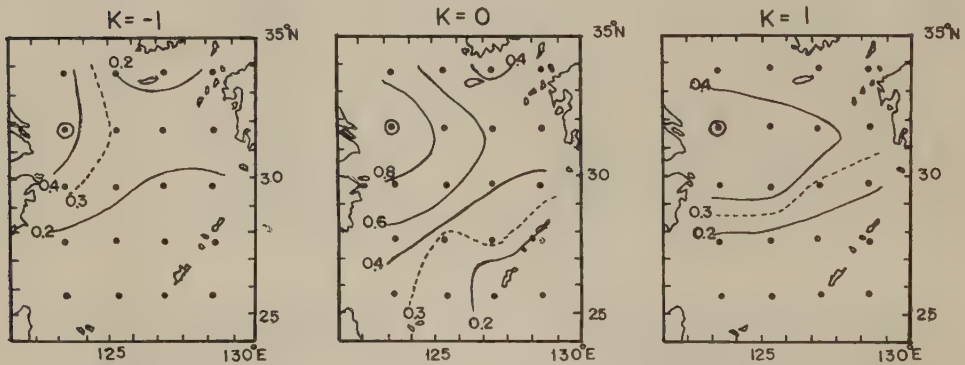


Fig. 7. Crosscorrelation coefficient for Case II-M. Reference area is Area 13.
 k is number of lag.

markedly with the number of lag and the value more than 0.6 is obtained for lag number of zero only. The characteristic features of the distribution for lag numbers of zero and three (lag is one month) in Case II-T are found for lag numbers of zero and one in this case.

The partial coherence and the phase lag (BENDAT and PIERSOL, 1966) are computed for two reference areas, Area 1 and Area 13. For higher frequency bands, the comparison with Case II-T is not possible, but the characteristic

features in the distribution for lower frequency bands are the same as those in Case II-T. In a word, the advection by the Kuroshio and the extension of the coastal water are shown by the distribution, but the relation of phase lag is against such processes in many areas. Thus, common deductions are obtained for ten-day anomalies and for monthly anomalies when lower frequency bands are discussed.

5. Spectral analysis of ten-day anomalies in the Kuroshio region (Case I-T)

Some discussions were made on the transmission of ten-day anomalies in 2° quadrangle in the Kuroshio region in the previous report. As 2° quadrangle is thought to be too large to discuss the effect of advection, four 1° quadrangles (Areas 1 to 4) are taken along the axis of the Kuroshio (Fig. 1). Then, the results are expected to show the effect with less distortions. The analysis is made for monthly anomalies as well, but the results for lower frequency bands are not different from those for ten-day anomalies.

Residual spectra are obtained by removal of the contribution by Area 11,

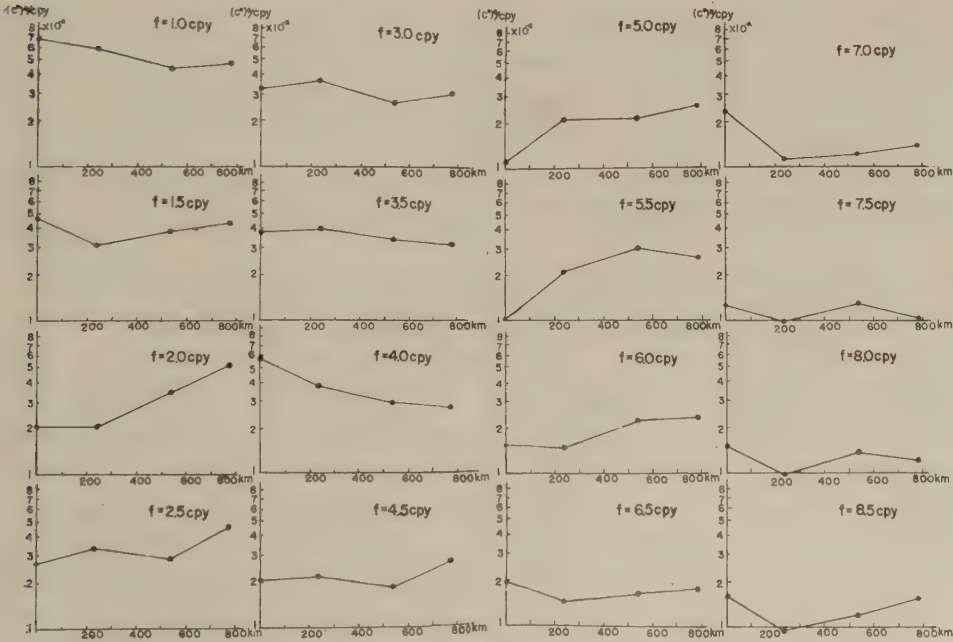


Fig. 8. The change of the spectral density with the distance from Area 1 (Case I-T).

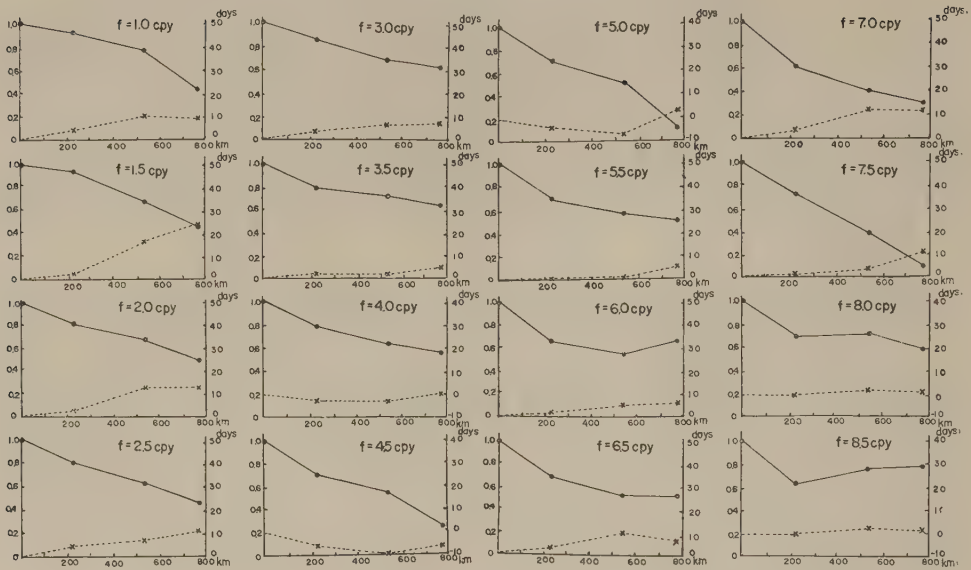


Fig. 9. The change of the partial coherence (full line) and the phase lag (broken line) with the distance from the reference area, Area 1 (Case I-T).

the source of the coastal water. Therefore, the spectrum is to be constant if anomalies are transmitted by advection. Fig. 8 shows the change of the spectral density with the distance from Area 1. The spectral density is not constant, but decreases or increases with the increase of the distance. This means that other effects than advection are not negligible. However, the change is slight for some frequency bands. Fig. 9 shows the partial coherence and the phase

Table 2. Current speeds estimated from the change of phase lag in the Kuroshio region (Case I-T). f (cpy) is frequency, u (cm/sec) northeastward current speed, δ (radian) root mean square of deviations from the assumed linear relation.

f	u	δ	f	u	δ
1.0	76.7	0.0330	5.0	-383.7	0.334
1.5	43.4	0.0796	5.5	229.6	0.167
2.0	62.2	0.0727	6.0	119.8	0.0539
2.5	83.1	0.0319	6.5	94.8	0.286
3.0	103.1	0.0544	7.0	61.8	0.237
3.5	199.4	0.0514	7.5	99.8	0.270
4.0	-418.6	0.138	8.0	-26100	0.175
4.5	-98.6	0.225	8.5	67.9	0.104

lag. The partial coherence decreases with the increase of the distance from Area 1, but most of the value is greater than the approximate 95% confidence limit, 0.42, and a linear relation is deduced. The phase lag must increase with the distance from Area 1 when the anomaly is transmitted by advection. Though the feature is found for most frequency bands, it decreases for some frequency bands. The current speed is computed by the method of least squares on the assumption that the phase lag is proportional to the distance from Area 1 (Table 2). The computed speed has reasonable values and the deviation from the assumed linear relation is slight for frequency bands of 1.0-3.0 cpy, 6.0 cpy and 8.5 cpy. The mean value of the current speed for those frequency bands is 73.7 cm/sec (about 1900 km/month). This result suggests that the assumption is valid for those frequency bands though the reason is not made clear. In this computation, the current speed is not assumed to be variable. This is not reasonable and it is considered to be one of reasons for unreasonable results.

6. Spectral analysis of ten-day anomalies in the coastal water region (Case I-T)

In the previous report, the distribution of coherence and phase lag of ten-day anomalies in 2° quadrangle in the coastal water region was discussed. The results were not satisfactory and in this section, the analysis for those in 1° quadrangle is tried to see how the coastal water spreads. The area considered here are Areas 5 to 11 and Area 11 is taken to be the source of the coastal water.

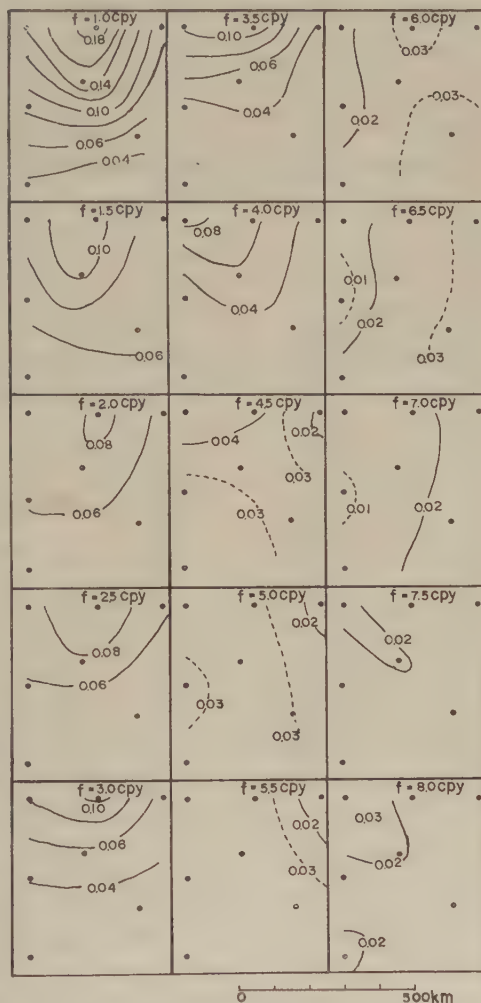


Fig. 10. The distribution of the spectral density ($^{\circ}\text{C}^2/\text{cpy}$) in the coastal water region (Case I-T).

Residual spectra are obtained by removal of the contribution by Area 1, the source of the Kuroshio water. Fig. 10 shows the distribution of the spectral density, which decreases southward or southeastward. For lower frequency bands, the greatest value is found at Area 10 and the decrease is more marked. It may be better to take Area 10 as the source of the coastal water. If the



Fig. 11. The distribution of the partial coherence (left) and the phase lag in days (right) referred to Area 11 in the coastal water region (Case I-T). Coherences are insignificant at approximately 95% significance level in shaded part, where values of phase lag are parenthesized.

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coastal water is assumed to be spread by diffusion, the spectral density must decrease exponentially with the distance from the source. The feature is found, but most of the value of diffusion coefficient is much greater than expected value. For 1.0 cpy, the value is approximately 10^8 C. G. S. which is a reasonable value for the phenomenon of such a scale. It is possible to ascribe the slight decrease of the spectrum to the advection. And the feature is more marked for higher frequency bands.

The distribution of the partial coherence and the phase lag referred to Area 11 (Fig. 11) are nearly the same as the distribution for Case II-T. The partial coherence decreases with the increase of the distance from Area 11 and the decrease is independent of the direction from the reference area. The decrease is more marked and the linear relation is restricted in smaller region for higher frequency bands. Phase lag does not increase linearly with the distance from the reference area. This neither support diffusion nor advection.

The deduction based on the distribution of the spectral density is different from that derived from the distribution of the phase lag. Thus, it is not concluded that the effect of the coastal water are transmitted by diffusion or advection. Maybe, the combined effect should be taken and other effects caused by the exterior are important.

The analysis is also made for monthly anomalies, but the results for lower frequency bands are nearly the same as those described above.

7. Concluding remarks

Comparison of the results of spectral analysis is made between four cases which have various scales of time and area. The results for 1° quadrangle are similar to those for 2° quadrangle, and for lower frequency bands, the results for ten-day anomalies are similar to those for monthly anomalies. This gives us an information on the scale of the variation of sea surface temperature in the East China Sea. Advection by the Kuroshio and diffusion of the coastal water are discussed based on the results of the spectral analysis of ten-day anomalies in 1° quadrangle. The results are not improved as compared with those in the previous report. Simple assumptions are one of the causes and other factors are considered to be important.

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Partial Pressure of Carbon Dioxide in the Atmosphere and in Sea Water over the western North Pacific Ocean

By

Tsutomu AKIYAMA

Japan Meteorological Agency

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Abstract: Following the measurements of pH and total alkalinity in 1967, partial pressures of carbon dioxide in the atmosphere (p_{CO_2}) and in surface ocean water (P_{CO_2}) over the western North Pacific Ocean were determined by an infrared absorption method in January—March, 1968. Observed values of p_{CO_2} are in the range between 316 and 334 ppm, being 324.1 ppm on an average. P_{CO_2} are in the wider range between 245 and 413 ppm, being nearly 330 ppm on an average. Generally high value of p_{CO_2} observed at the higher latitudes decreases gradually towards the equator. While P_{CO_2} is remarkably high at the lower latitudes around the equator. The partial pressures of carbon dioxide in the atmosphere and in the surface water differ much each other, ranging from -83 to +91 ppm ($P_{CO_2} - p_{CO_2}$) from location to location. Thus the transfer of carbon dioxide through the air-sea interface seems to be considerably slow.

1. Introduction

Carbon dioxide in various reservoirs has been studied by many investigators in views of the geochemical significance. In the atmosphere and the ocean, carbon dioxide is removed by biosynthetic utilization and weathering processes. It is supplied by respiration of living organisms, decomposition of organic matters, volcanic activity and combustion of fossil fuels. It is considered that the exchange of carbon dioxide between the atmosphere and the ocean occurs so as to equilibrate the partial pressure in both reservoirs. In the ocean, the carbonate equilibria are attained by a thermodynamic balance depending on the temperature, pH and salinity of sea water. In addition, the distribution of carbon dioxide is controlled by water movement and mixing.

In the area of the western North Pacific Ocean, the partial pressure of carbon dioxide in the atmosphere (p_{CO_2}) and that in sea water (P_{CO_2}) have been determined by several workers, WATERMAN (1964), AKIYAMA (1966) and MIYAKE and SUGIMURA (1968) by an infrared absorption method, but these are not enough

to cover the wide area to discuss detailed distributions.

In the present work the author intends to investigate the following problems, (1) pCO_2 at the present time to estimate the long term variations in future, (2) Pco_2 as a parameter of water mass, (3) transfer of carbon dioxide through the air-sea interface and (4) short term variations.

2. Method of measurement

An infrared analyser automatically and continuously determines the concentration of carbon dioxide in the air based on a differential measurement of the absorption of infrared energy. A simplified functional diagram of the analyser is shown in Fig. 1. The analyser used in the present work (Beckman-

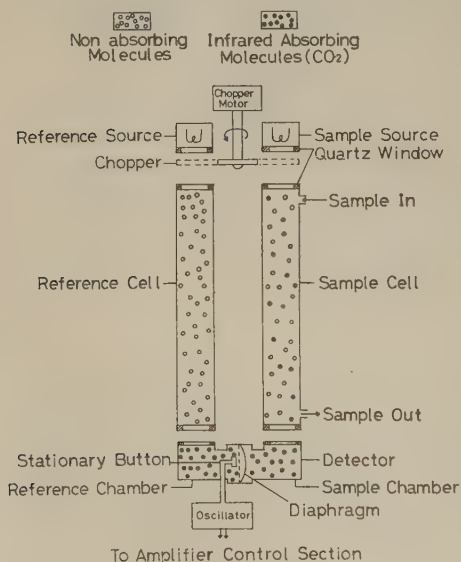


Fig. 1. A functional diagram of the infrared analyser.

Toshiba Model IR-315) was partly improved from its standard model because a high accuracy of the measurement within 1 ppm was required. Main points of reform are as follows.

1) A standard cell of 10 inches optical path length was replaced by more longer one of 25 inches length.

2) A range of measurement covering from 0 to 400 ppm was altered to a range of 250–400 ppm for a full scale.

3) To remove a water vapour in the sample gas an electronic cooler (Hayakawa Denki Model TE-33) which enables to keep the temperature of sample gas always at 1.5°C was inserted on a sample path instead of a drying column.

4) In a shipboard operation an instability of the frequency of the ship's a. c. power supply is a serious problem for an accuracy of the measurement. A precise frequency regulator (Nihon-Denki Model NJD-231 E) which keeps a constant frequency of 60 ± 0.1 c/s was provided for the operation of the analyser and amplifier section.

The analyser was installed steadily on the floor of the shipboard laboratory of the R. V. "Ryōfū-maru" of Japan Meteorological Agency as shown in Fig. 2.

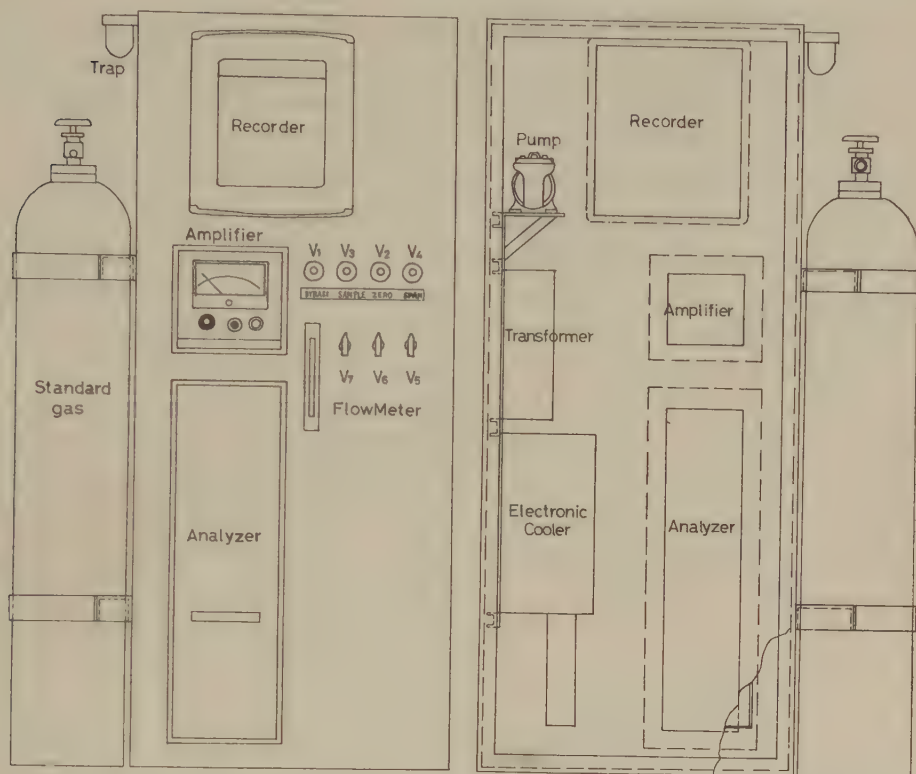


Fig. 2. The frontal and behind views of the infrared analyser installation.

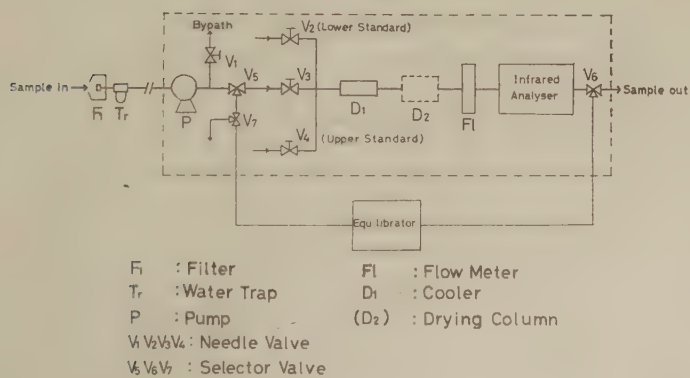


Fig. 3. An overall arrangement of the measuring system for measurements of carbon dioxide in the atmosphere and in sea water.

An overall arrangement for the measurements of p_{CO_2} and P_{CO_2} by an equilibrator measurement is schematically shown in Fig. 3. The intake position of the air sample must be decided in due consideration of good ventilation and of no contamination by the smoke from the engine.

An equilibrator measurement for sea water

In order to measure the partial pressure of carbon dioxide in sea water (P_{CO_2}) an equilibrator was specially designed as shown in Fig. 4. An equilibrium

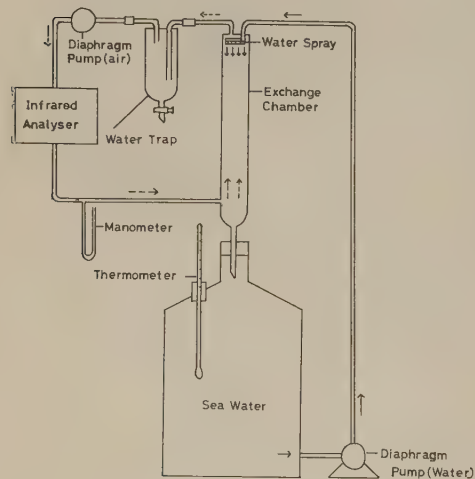


Fig. 4. A construction of the equilibrator for the measurement of carbon dioxide partial pressure in sea water.

of carbon dioxide between the sample water and the circulating air is attained in an exchange chamber by the contact of the shower of the water sample and the circulating air flowing counterwards. The equilibrium is ascertained by a constant value on the recording chart with time. Normally it takes about ten minutes to reach an equilibrium when the air circulates at the flow rate of 1 l/min. The larger the volume of sample water is as compared with the volume of circulating air, the more quickly and correctly the equilibrium may be attained. In the present equilibrator, volumes of the sample

water and of the circulating air are approximately 10 l and 2 l, respectively. On the path of the circulating air a manometer is mounted just behind the analyser to read off the pressure of circulating air in the sample cell.

3. Correction factors and their estimations

Corrections for the recorder readings are to be applied for the following factors.

1) Correction for the instrumental error (C_i)

Prior to the measurement the analyser should be calibrated over a full span by the carbon dioxide standard gasses of various concentrations which are accurately known. A value to be corrected for the observed reading is known from the calibration curve.

2) Correction for the pressure in the sample cell (C_p)

In the measurement of the atmospheric air, the outlet of the sampling system is opened to the atmosphere to maintain the barometric pressure in the sample cell. When the concentration of carbon dioxide is expressed in ppm by volume as the partial pressure, no correction is necessary.

In the equilibrator measurement of P_{CO_2} the pressure of circulating air may possibly change during the equilibration due to the addition or extraction of dissolved gases in sample water by the circulating air. The difference between the resulting pressure of the circulating air and the barometric pressure detected by a manometer should be corrected.

3) Correction for the water vapour (C_h)

Water vapour in sample is almost removed by condensation of the vapour in a cooler which can automatically maintain the temperature of sample at 1.5°C . Consequently the air in the sample cell still contains about 7.8 mb of water vapour. Therefore, the partial pressure of carbon dioxide exerted in the natural atmospheric air can be obtained after correction for removal of water vapour. The partial pressure of carbon dioxide in dry air is obtained by multiplying the factor of 1.008 to the observed value.

4) Correction for the change of water temperature during the equilibration (C_t)

This correction is applied only to the equilibrator measurement of water. The temperature of the sample water may possibly change during the equilibration from the temperature of the water in the ocean. The correction for the temperature change was not applied in the present investigation, because the change of water temperature beyond 0.5°C was not encountered. For the further measurement of P_{CO_2} , however, the correction value for 1°C temperature change should be experimentally decided in use of the present analyser.

5) Correction for the carbon dioxide exchange between the sample water and the circulating air (C_e)

When the partial pressure of carbon dioxide in the initial circulating air differs much from that in sample water, the exchange of carbon dioxide may possibly cause an error. In the present equilibrator the amount of the total carbon dioxide is estimated to be about 1,000 times of that in the circulating air, and the effect therefore may be considered to be almost negligible.

The whole corrections for the measurement of the atmospheric air are summarized and shown in a graphical expression versus dew point temperature (Fig. 5). The overall uncertainty being concerned with the corrections of C_t , C_p

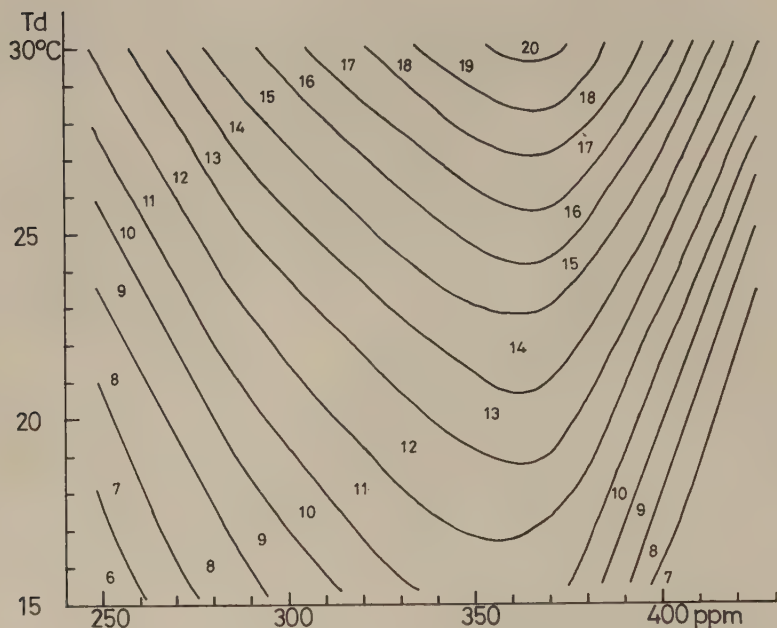


Fig. 5. A graphical expression of correction value (ppm) to be subtracted from the observed partial pressure for the instrumental error and the error due to the humidity in sample air.

and C_h may be estimated to be less than 2 ppm.

For the equilibrator measurement of sea water all corrections mentioned above must be applied to the observed value. The uncertainty for the measurement of sea water may be not more than 5 ppm as a whole.

4. Results and Discussions

Atmospheric carbon dioxide shows some variations with time and location in accordance with the exchange of carbon dioxide between the atmosphere and the other reservoirs such as the hydrosphere and the biosphere, and with the production of carbon dioxide by combustion of fossil fuels.

The partial pressure of carbon dioxide in the atmosphere (p_{CO_2}) over the western North Pacific Ocean was measured continuously during the CSK (Co-operative Study of the Kuroshio and Adjacent Regions) cruise of R. V. "Ryōfūmaru" in January-March, 1968. Values of p_{CO_2} were observed every 3 hours from the continuous record immediately after the standardization of the instrument was done, since the correction value due to changes of the barometric

pressure and of the water vapour pressure were accurately obtained only at the map time when routine weather observations were carried out. Each observed value may be regarded as mean value during the period of 3 hours, because the sudden change in carbon dioxide partial pressure was scarcely encountered and drifts of a zero point and of a span did not exceed the limit of 1 ppm during the period. Results of observation show that p_{CO_2} ranges between 316 and 334 ppm as shown in Fig. 6. Along the meridional direction p_{CO_2} generally decreases

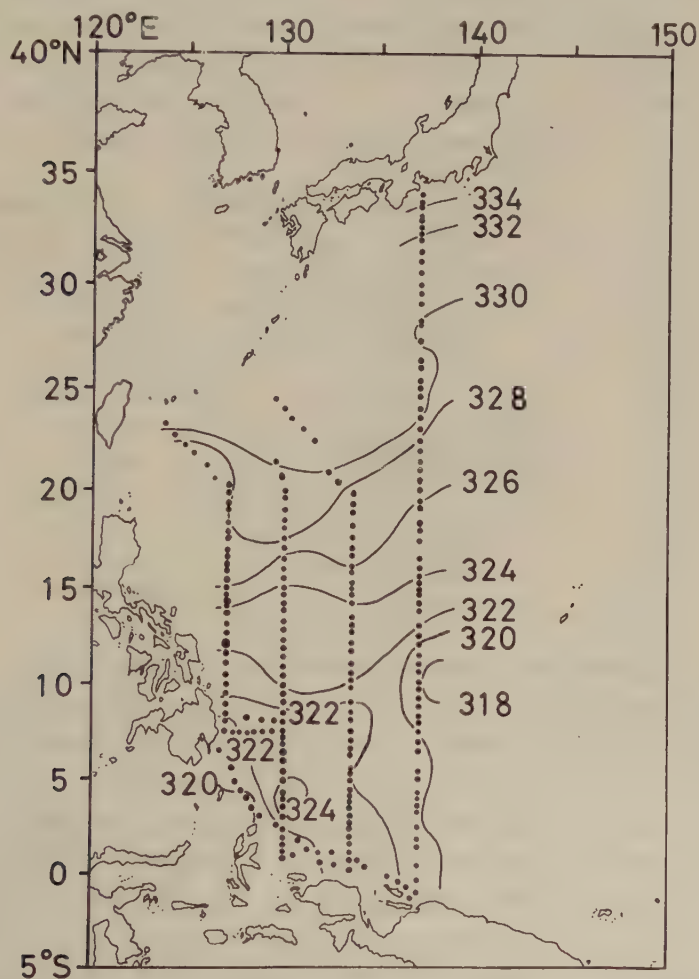


Fig. 6. The distribution of partial pressure of carbon dioxide (ppm) in the atmosphere (p_{CO_2}) in the western North Pacific Ocean in January-March, 1968.

toward the equator, the rate of which is higher in the belt between 15° and 20°N . Higher values of pco_2 at higher latitudes may be mainly attributed to the supply of carbon dioxide to the atmosphere from the combustion of fossil fuels. A pattern of pco_2 distribution is similar to that of the barometric pressure. This may be related to the fact that the north-west monsoon prevailed to the extent of 15°N in winter season. The atmospheric carbon dioxide of high concentration at the higher latitudes may be transported toward the south with the movement of air masses. Comparing with the values of pco_2 between observation lines of 127°E and 137°E , the former is higher about 3 ppm than the latter in the same latitude. The mean concentration of the atmospheric carbon dioxide over the observed area was estimated to be 324.1 ppm with a standard deviation of ± 2 ppm. This coincides closely with that (324.3 ppm) in the previous work

Table 1. Mean values and their standard deviations of the partial pressure of carbon dioxide in the air over the western North Pacific Ocean.

Latitude	No. of Meas.	pco_2 in air (ppm)
30-34° N	12	331.6 ± 1.6
25-30	10	329.0 ± 1.5
20-25	27	328.4 ± 1.7
15-20	41	326.0 ± 2.0
10-15	43	322.1 ± 2.0
5-10	50	321.7 ± 1.7
0- 5	46	321.8 ± 1.5
0- 1°S	6	320.7 ± 1.8
1°S -34° N	235	324.1

by the present author (1966). MIYAKE and SUGIMURA (1968) reported values of Pco_2 ranging from 317 to 326 ppm. WATERMAN's value (1964) seems to be a little lower on an average by about 5 ppm than the present work. Discrepancy among pco_2 values reported by different workers may be partly due to the seasonal and locational differences of observations. The attempt to detect the diurnal variation of pco_2 above the ocean was done at a location of $130^{\circ}02'\text{E}$, $11^{\circ}58'\text{N}$ for three days, but variations beyond 1 ppm was not found during the period.

The partial pressure of carbon dioxide in surface water (Pco_2) was measured at 43 stations as shown in Fig. 7. Results showed a wider range of Pco_2 from 245 to 413 ppm. Lower values were found in the area of higher latitudes than 10°N along 137°E meridian, while higher values were observed in the area

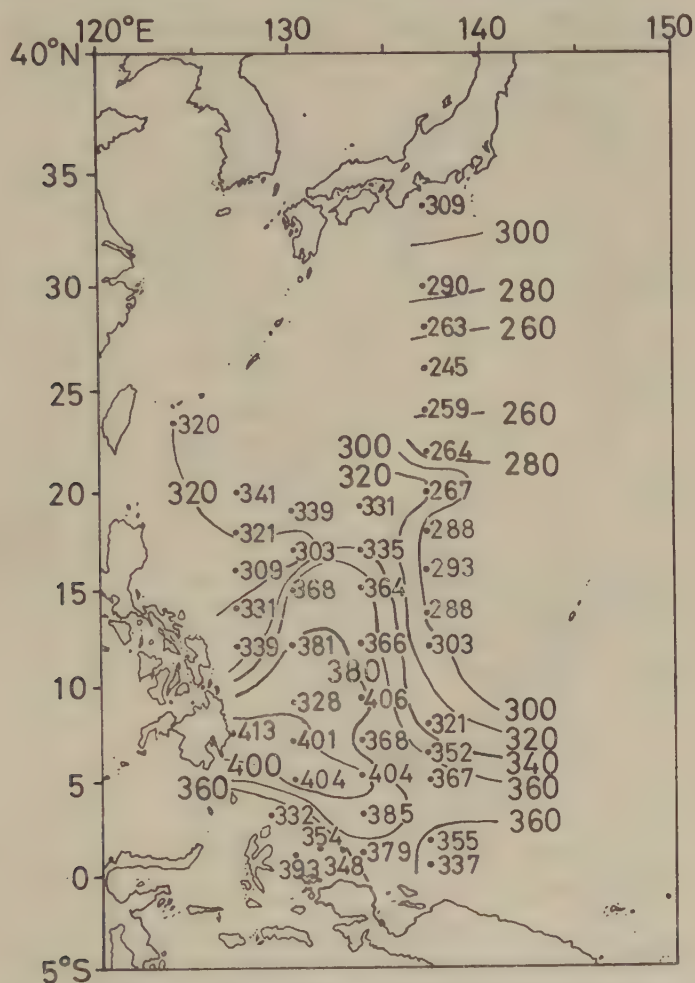


Fig. 7. The distribution of partial pressure of carbon dioxide (ppm) in surface water (Pco₂) in the western North Pacific Ocean in January-March, 1968.

of lower latitudes than 15°N. The highest belt was located around 5°N where the North Equatorial Countercurrent prevailed. In the area east of the Ruzon Island relatively lower values of Pco₂ was found. As compared with the global distribution of Pco₂ reported by KEELING (1968), Pco₂ obtained in the present work is generally high and fluctuates widely with locality. In general it seems that Pco₂ shows a marked dependency on latitudes. It is evidently noticed that the variations of Pco₂ were in parallel with changes of water temperature as

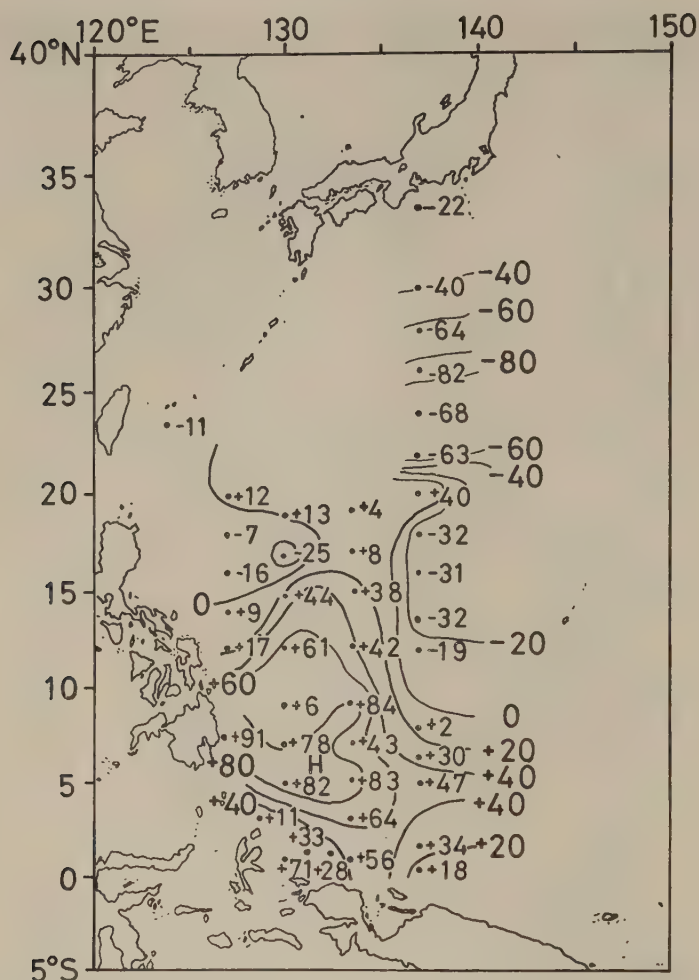


Fig. 8. Difference of partial pressure of carbon dioxide (ppm) between those in the atmosphere and in surface water ($P_{CO_2} - p_{CO_2}$).

shown in Figs. 10 and 11. The correlation coefficient between Pco_2 and water temperature was estimated to be 0.57. Thus the range of variation in Pco_2 was larger than that which can be accounted for the temperature change alone. Let us consider the order of variation in Pco_2 due to changes of water temperature and salinity. From the previous work by the present author (AKIYAMA *et al.*, 1968), following observed values which are related to carbon dioxide system are cited.

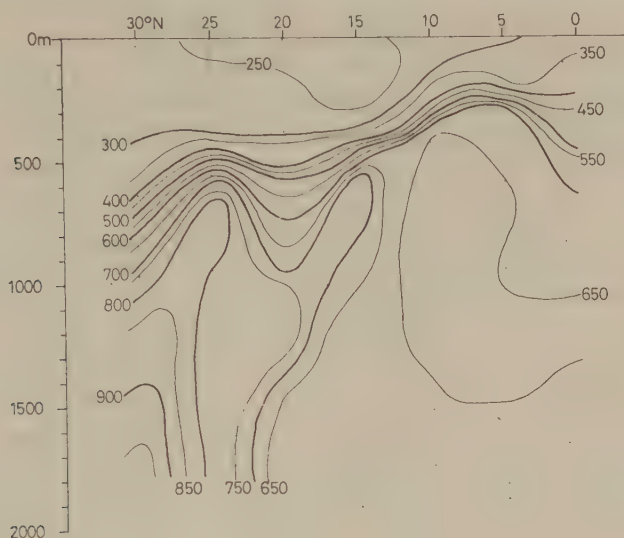


Fig. 9. Vertical distribution of partial pressure of carbon dioxide (ppm) in sea water in the section of 137°E predicted from measurements of pH and total alkalinity in January-March, 1967.

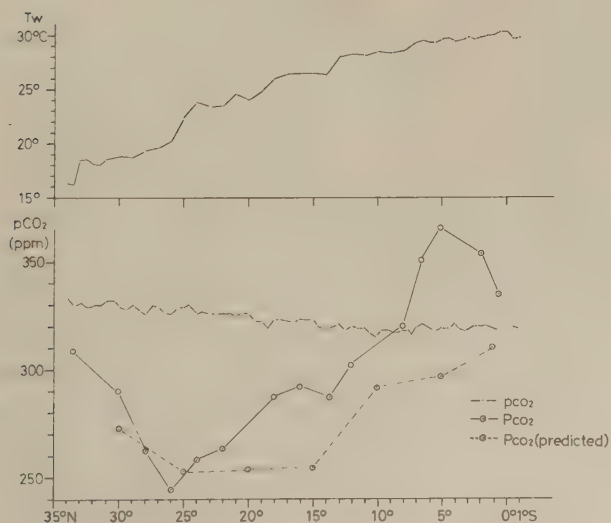


Fig. 10. Partial pressure of carbon dioxide in the atmosphere and in surface water along the longitude of 137°E.

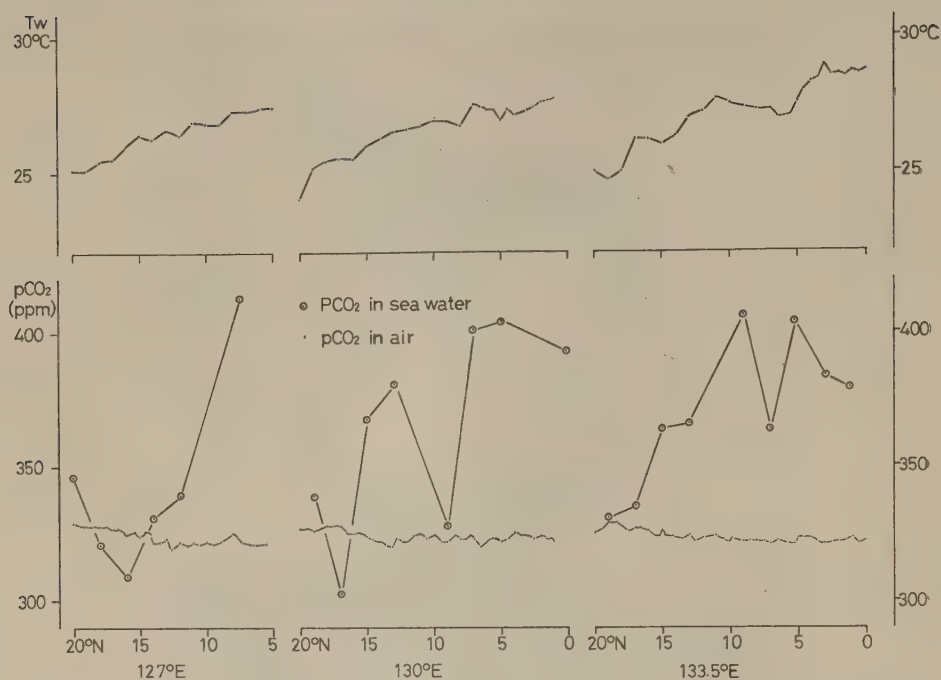


Fig. 11. Partial pressure of carbon dioxide in the atmosphere and in surface water along the longitudes of 127°E, 130°E and 133.5°E.

Station	Location	Tw (°C)	pH	S (%)	Total CO ₂ (mmol/l)
A	137°-00'E 25°-00'N	22.5	8.30	34.906	2.03
B	137°-00'E 5°-00'N	28.3	8.20	34.380	2.03

Predicted values of P_{CO_2} based on the results of pH and total alkalinity measurements are 237 and 332 ppm respectively at stations A and B. On the other hand, P_{CO_2} measured directly by the present method are 246 and 367 ppm respectively. The difference of P_{CO_2} detected between stations A and B is 121 ppm, while it is expected to be 95 ppm from a knowledge of carbon dioxide equilibrium. It is suggested that the large part of geographical difference in P_{CO_2} (about 80%) may be attributed to changes of thermodynamic variables in this illustration.

Other factors should be certainly in consideration of P_{CO_2} distribution. High value of P_{CO_2} is often found in the upwelling area where the carbon dioxide is supplied from the deep to the surface. A belt of high P_{CO_2} along the latitude

of 5°N may be related to the upwelling of deep water, where the formation of vortex is reported. In connection with the vertical mixing MIYAKE and SUGIMURA (1968) reported the higher correlation between P_{CO_2} in surface water and the depth of pycnocline in the oceans. Biological utilization and regeneration may also affect the distribution of P_{CO_2} . The decrease of P_{CO_2} is to be generally expected in the productive area. Nevertheless, the results show a rather high P_{CO_2} in the area around equator where much plankton diatoms inhabit. It is obliged to be considered that other factors such as temperature rise or vertical mixing may exceed the biological effect in the area.

The disequilibrium values ($P_{CO_2} - p_{CO_2}$) observed in the present work are fairly large, being in the range between -82 and +91 ppm. It is likely, however, that in the lamina layer an equilibrium may be attained to the further extent. When P_{CO_2} and p_{CO_2} differ each other, there will be a net flux of carbon dioxide which is proportional to the difference of partial pressure from the phase of high one to the other. MIYAKE and MATSUO (1963) estimated theoretically the increase of carbon dioxide in the air due to the escape of carbon dioxide from the sea surface according to the data reported by TORII *et al.* (1959) in the Antarctic Ocean, and showed the maximal increase of 0.9 ppm in the air for steady state when P_{CO_2} exceeds by 200 ppm more than p_{CO_2} . Several factors controlling the transfer rate have been considered. The low molecular diffusion constant in the liquid phase compared with that in the gaseous phase could be an important limiting factor of transfer. It is also well known that the turbulence caused by the wind accelerates the rate of transfer. According to SUGIURA *et al.* (1963) values of rate constant for the carbon dioxide transfer reported in literatures differ widely, probably because of the turbulence effect. The values of disequilibrium detected in the present work are relatively high than those obtained by TAKAHASHI in the North Atlantic Ocean (TAKAHASHI, 1961). Consequently the large disequilibrium may be an evidence of the slow rate transfer of carbon dioxide through the air-sea interface.

Total carbon dioxide which is independent on the hydrodynamic variables may be more useful than P_{CO_2} as indices of water masses. In order to consider the carbonate system quantitatively after the model of Saruhashi's table (SARUHASHI, 1955), tables for conversions of carbonate alkalinity to P_{CO_2} and of P_{CO_2} to inorganic total carbon dioxide are readily provided by calculation of the electronic computer (HITAC 5020) at intervals of 0.01 in pH unit and of 2°C in temperature at various chlorinities. Conversion tables will be reported in another paper.

Acknowledgements: The author wishes his hearty thank to Prof. Yasuo MIYAKE, Tokyo Kyoiku University, for his valuable advice and comment. He is indebted much to Messrs. T. SAGI and T. YURA, Japan Meteorological Agency, for their cooperation in field measurements and critical discussions.

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The Distribution of Dissolved Oxygen and Phosphate Phosphorus in the adjacent Seas of Japan

By

Tsutomu AKIYAMA

Japan Meteorological Agency

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Abstract: Annual mean values and their standard deviations of dissolved oxygen and phosphate phosphorus in the adjacent seas of Japan are calculated in each square degree based on the data observed for 10 years from 1956 to 1965 by the Japan Meteorological Agency. General features of distributions and annual mean values in some water masses are shown in figures and tables. The content of oxygen minimum and the depth of its appearance differ locally, being in the range between 0.6 and 1.6 ml/l and between 600 and 1,500 m, respectively. The *in situ* density of sea water at the depth of oxygen minimum is in the range between 27.25 and 27.50. The phosphate maximum occurs in the range between 2.8 and 3.8 $\mu\text{g-atoms/l}$ in content at the same depth of dissolved oxygen minimum.

1. Introduction

Since 1953 chemical elements such as the dissolved oxygen, the phosphate phosphorus and the silicon in the adjacent seas on the Pacific side of Japan have been determined simultaneously in cooperative observations by the Japan Meteorological Agency, the Hakodate Marine Observatory, the Kobe Marine Observatory, and the Nagasaki Marine Observatory. Observations have been carried out periodically in winter (January-March) and summer (July-September) every year and in four seasons in some years. The data in each observation have been reported in the Results of Marine Meteorological and Oceanographical Observations published by the Japan Meteorological Agency with a brief explanation.

Although a large number of results of chemical analyses has been accumulated with other hydrographic elements up to present, a summarized study on the geographical distributions or the seasonal and annual variations of chemical elements has not yet been performed. KITAMURA and SAGI (1964, 1965) summarized the distributions of chemical elements south of Honshu, Japan. OHWADA

and YAMAMOTO (1966) studied also the distributions of the dissolved oxygen and phosphate phosphorus in the Japan Sea.

The present author attempted to obtain the general features of the distributions of dissolved oxygen and phosphate phosphorus in whole areas based on the data obtained for 10 years from 1956 to 1965. The present paper deals with the annual mean values and their standard deviations of dissolved oxygen and phosphate phosphorus in each square degree, the content of dissolved oxygen minimum and the depth at which the minimum is observed, the maximum content of phosphate phosphorus and the depth at which the maximum appears, and annual variations in various water masses.

2. Assessment of data

Values at standard depths of 0, 100, 200 m were estimated by interpolations of the observed values at each station. When several data were available in each square degree, mean value was adopted as a representative one in the year. Observation period and location more or less differ from year to year. The effects due to the drifts in time and location are not under considerations. In addition, numbers of data used in statistics are not equal in each square, therefore each mean value should be evaluated to be an approximate estimation. Besides the annual mean value, a standard deviation was calculated at each location and depth, which indicated the extent of annual variation of the content and the degree of the reliability of each mean value. The lowest content of dissolved oxygen and the highest content of phosphate phosphorus at each station on the vertical direction among the data obtained for 10 years were taken as the most probable values of oxygen minimum and phosphate maximum. For the reason it is assumed that the annual variation occurred actually in deep layer where the oxygen minimum occurs may be almost negligible and therefore the difference of content observed in each year may be mainly due to the sampling depth.

Annual variations in dissolved oxygen were examined at some locations of various water masses.

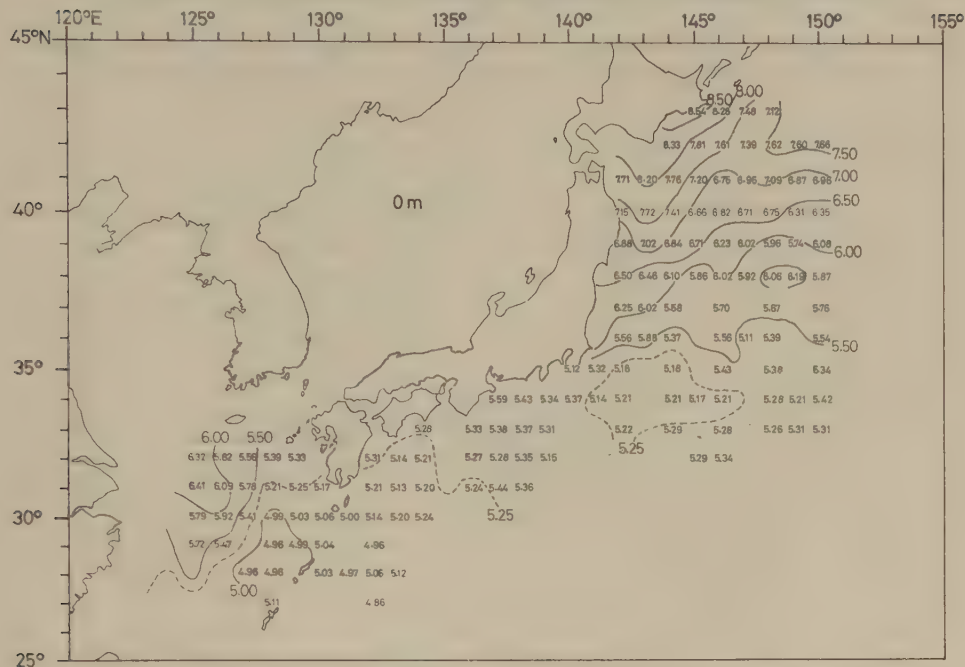
3. Results

3-1. *Dissolved Oxygen*

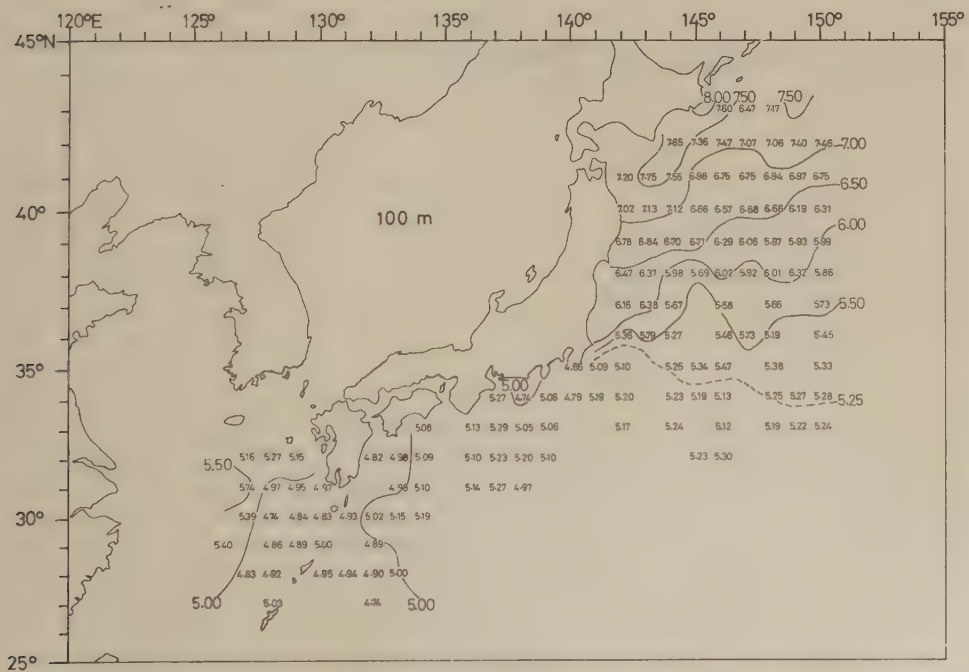
General features of distribution

The mean contents of dissolved oxygen in sea water for 10 years are shown

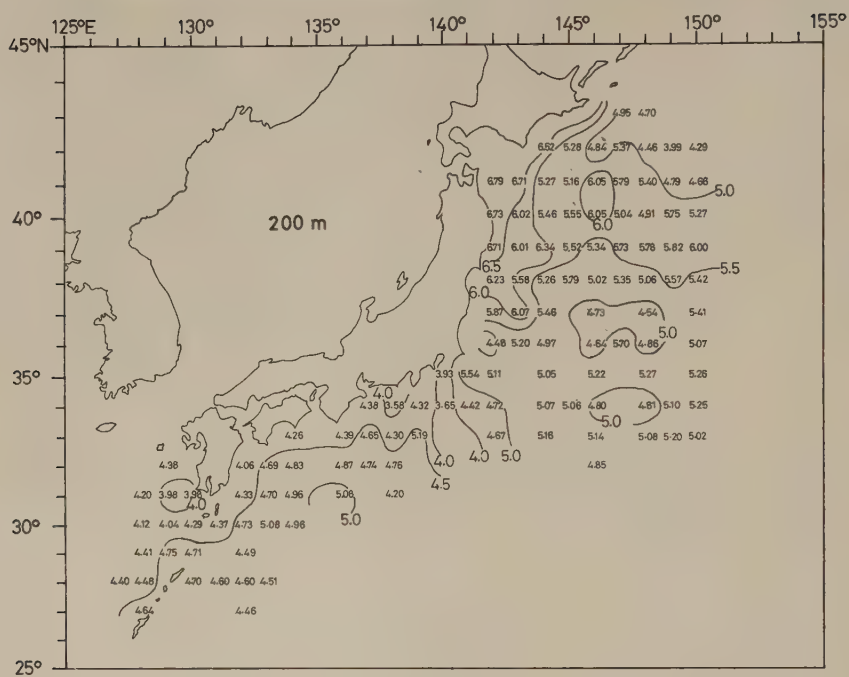
T. Akiyama: The Distribution of Dissolved Oxygen and Phosphate Phosphorus



1-a-1



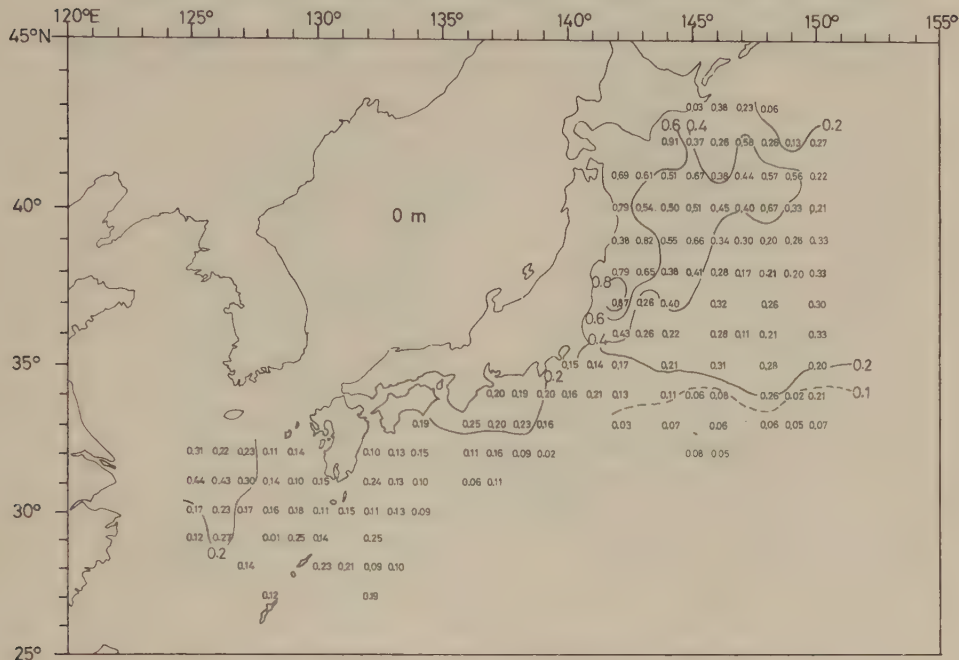
1-a-2



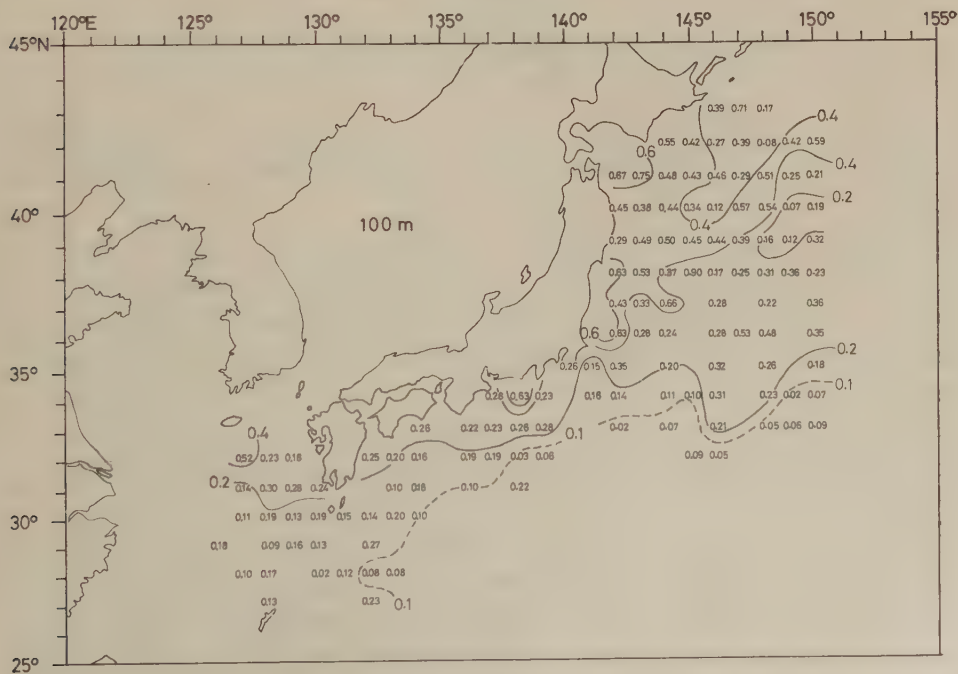
1-a-3

Fig. 1-a. Annual mean values of dissolved oxygen content in winter (ml/l).

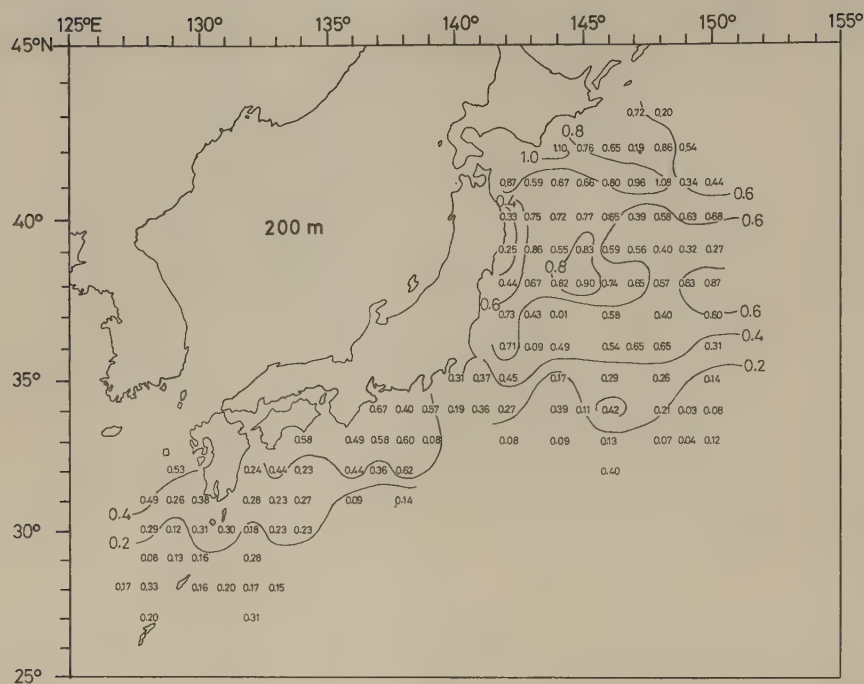
T. Akiyama: The Distribution of Dissolved Oxygen and Phosphate Phosphorus



1-b-1



1-b-2



1-b-3

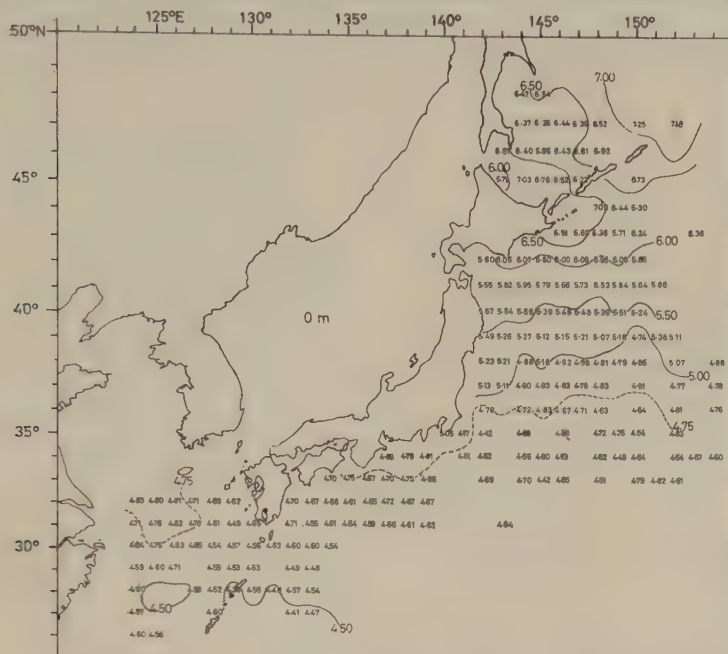
Fig. 1-b. Standard deviations from annual mean values in Fig. 1-a.

in every degree square in parts of winter and summer. The isoquants of oxygen contents are drawn for the convenience to look an outline of the general distribution.

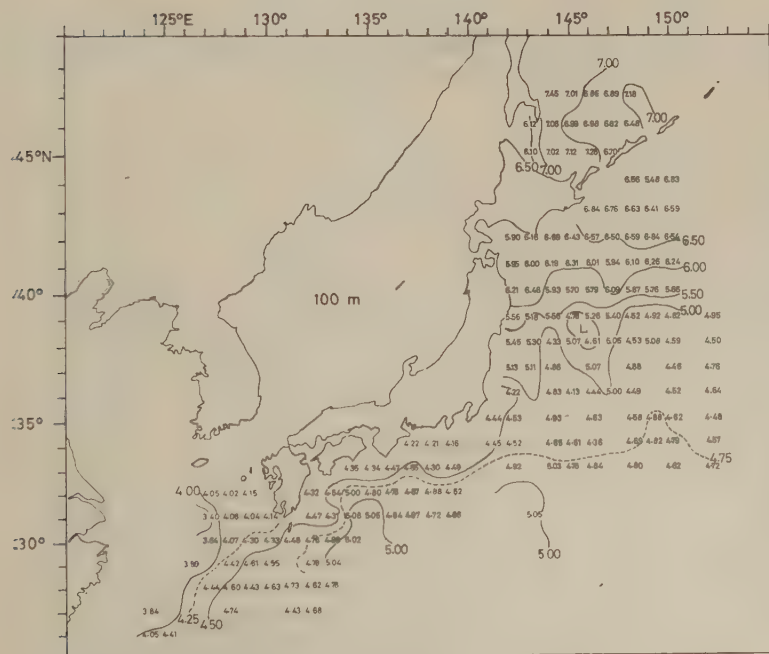
In waters of the Kuroshio and its south, the annual mean content of dissolved oxygen is lowest among water masses surrounding Japan. As the Kuroshio proceeds eastwards from the south of Kyushu to the east of Japan (150°E), dissolved oxygen increases by about 0.5 ml/l in winter, while little increase is found in summer. Higher contents of dissolved oxygen are found generally in cold waters of the Oyashio region. The highest content which may be regarded as original value for the Oyashio water is observed around the location of 42°N , 142°E .

In the coastal area west of 144°E the oxygen content is relatively high where the southward flow of the Oyashio prevails. In the offshore area east of 148°E the oxygen content is high, which reflects another branch of the Oyashio water. In the mixing zone of the Kuroshio and the Oyashio the oxygen content

T. Akiyama: The Distribution of Dissolved Oxygen and Phosphate Phosphorus



2-a-1



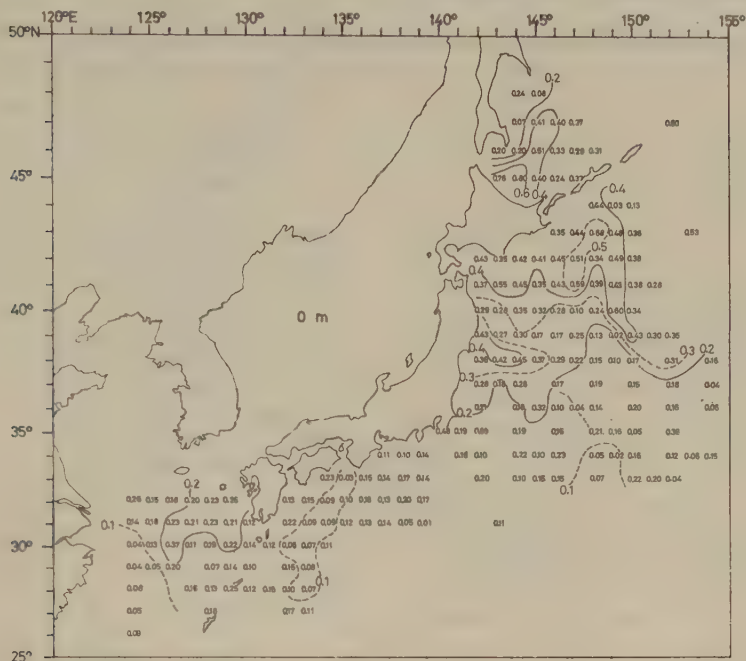
2-a-2



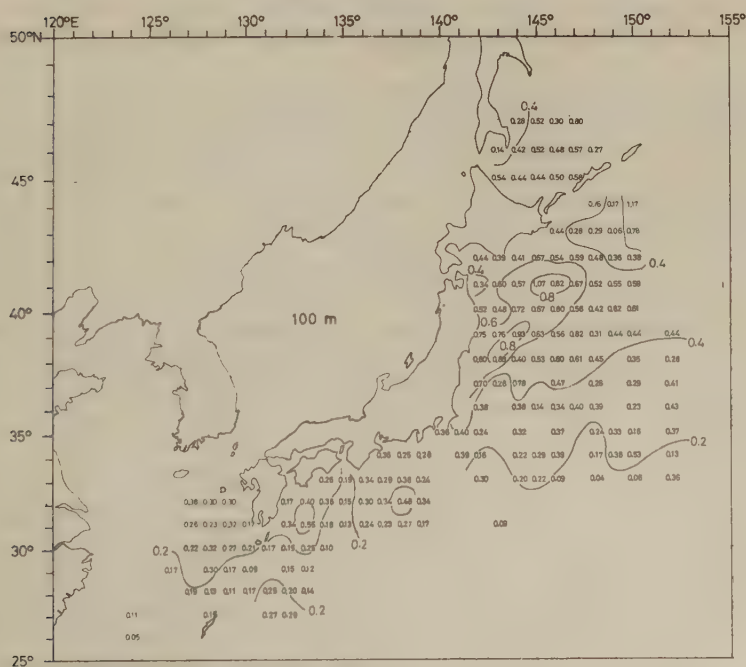
2-a-3

Fig. 2-a. Annual mean values of dissolved oxygen content in summer (ml/l).

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2-b-1



2-b-2



2-b-3

Fig. 2-b. Standard deviations from annual mean values in Fig. 2-a.

increases gradually towards the north in proportion to the mixing ratio of two water masses. Each isoquant of oxygen contents extends almost from the west

Table 1. Estimations of annual mean oxygen contents in various water masses around Japan (ml/l).

In Winter							
Standard depth (m)	Kuroshio		Oyashio		Tsushima W.C. west of Kyushu	Yellow Sea	Coastal W. south of Honshu
	(130° E)	(150° E)	coastal	offshore			
0	4.9	5.4	8.3	7.6	5.3	6.4	5.3—5.6
100	4.8	5.4	7.7	7.5	5.1	5.7	4.7—5.3
200	4.7	5.3	6.5	4.0	4.1	—	3.6—4.4
In Summer							
0	4.5	4.6	6.1	6.3	4.6	4.8	4.7—4.9
100	4.4	4.5	6.8	6.8	4.1	3.6	4.2—4.4
200	4.3	4.6	5.8	4.5	3.9	—	3.6—4.0

to the east with a little northwards component. The area with low oxygen content exists in isolation at the location of about 39°N, 145°E. The water mass in this area seems to be originated from the Kuroshio. In the East China Sea the oxygen content is high in a cold water mass originated from the Yellow Sea. Annual mean values in various water masses are summarized in Table 1.

Standard deviations of dissolved oxygen content

In order to estimate the annual variation of dissolved oxygen content at each location, standard deviations are calculated. In the Kuroshio region it is lowest, being less than 0.2 ml/l in the surface layer. The high standard deviation in the Kuroshio region more than 0.3 ml/l is observed around the location of 30°N, 146°E, where the cold water with rich dissolved oxygen appears occasionally. In the Oyashio and the mixed water region it is high and fluctuates locally ranging from 0.3 to 1.0 ml/l. Among them higher values more than 0.6 ml/l are observed in the coastal area south of Hokkaido and east of northern Sanriku district. The standard deviations are considerably high in the upwelling area at a location of 33-34°N, 138°E, and a little higher in the cold water region of the Yellow Sea.

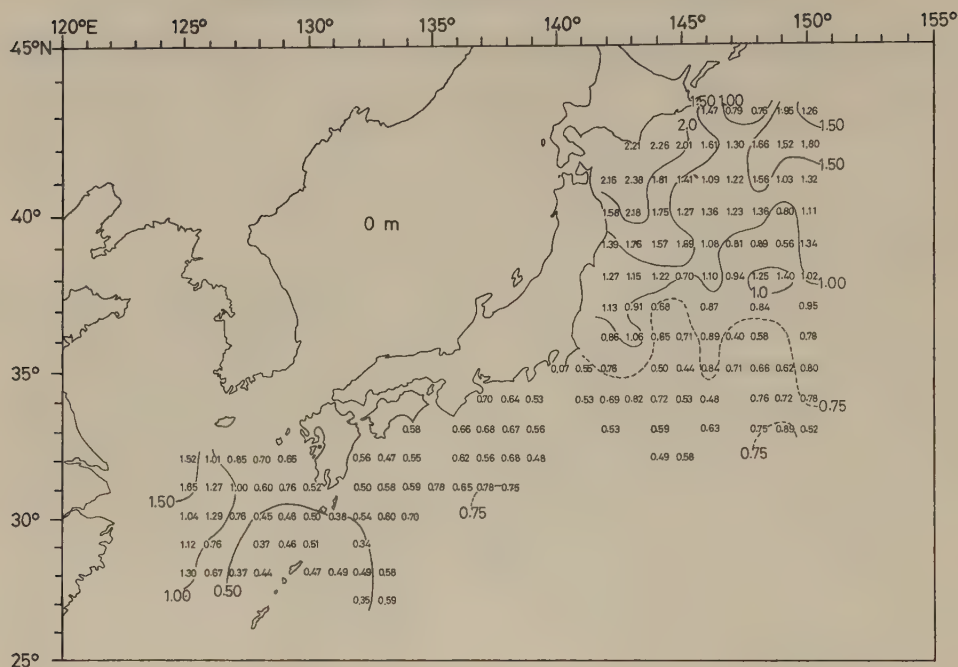
Seasonal variation of dissolved oxygen content in winter and summer

The dissolved oxygen content at the surface is higher in winter than in summer by 2.4 ml/l at the maximum in the Oyashio and by 0.4 ml/l at the minimum in the Kuroshio. At the depth of 100 m the difference in the oxygen content between both seasons becomes slightly less, being 1.9 ml/l and 0.2 ml/l in each water mass. The observed and saturated values of dissolved oxygen at the representative locations of the Kuroshio and of the Oyashio are estimated as shown in Table 2. It seems that the seasonal difference of oxygen content

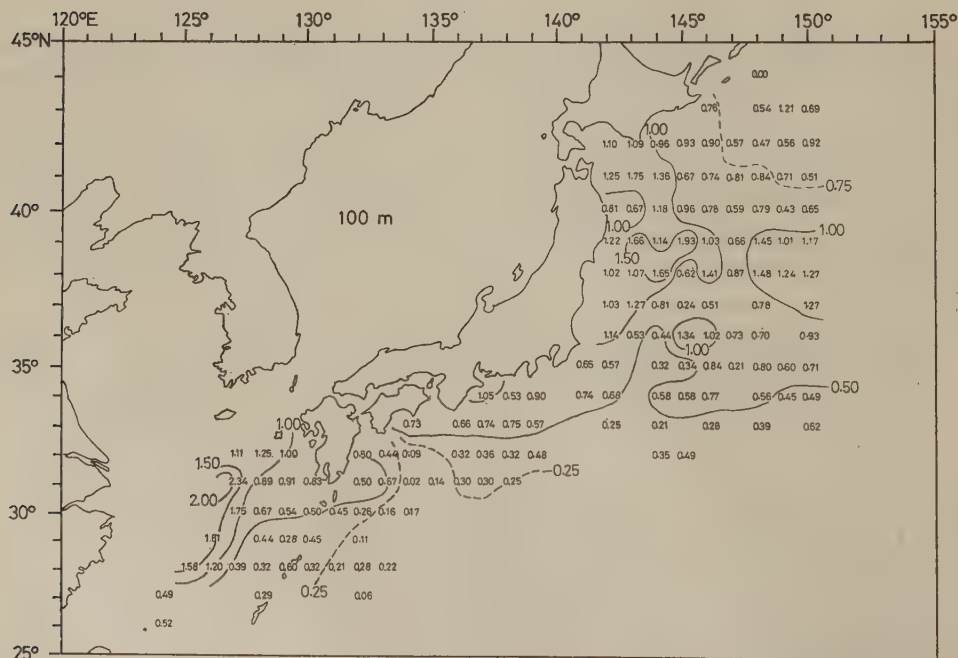
Table 2. Seasonal difference of dissolved oxygen content between winter and summer at stations in the Kuroshio and the Oyashio (ml/l).

	Location	Depth (m)	O ₂ (observed)			O ₂ (saturated)		
			W.	S.	(W.—S.)	W.	S.	(W.—S.)
the Kuroshio	28° N	0	4.96	4.59	0.37	5.19	4.59	0.60
	127° E	100	4.83	4.44	0.39	5.21	4.94	0.27
the Oyashio	42° N	0	8.35*	6.07*	2.26	8.12	5.78	2.34
	144° E	100	7.65	6.69	0.96	7.76	7.73	0.03

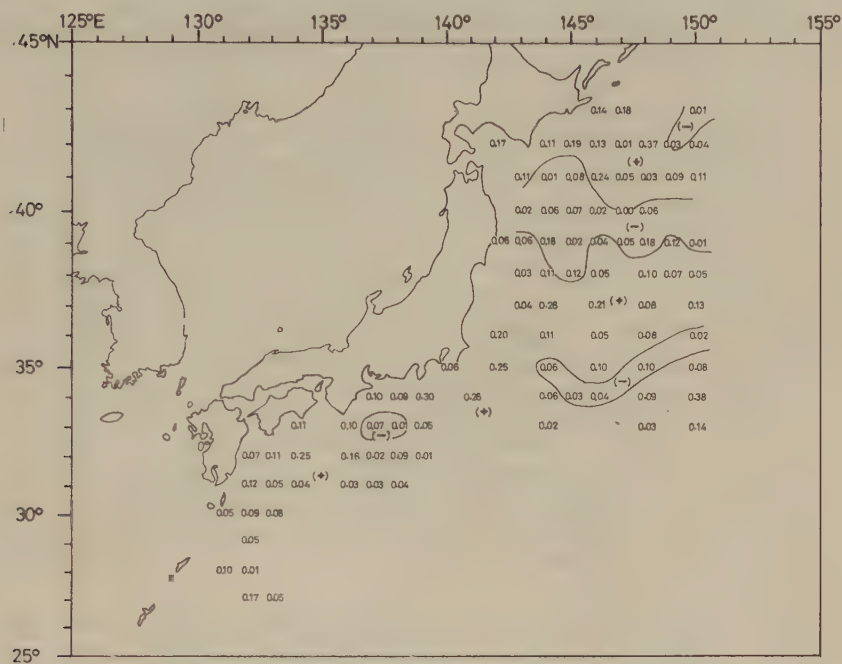
* super saturation.



3-1



3-2



3-3

Fig. 3. The seasonal difference of dissolved oxygen content in winter and summer at the depths of 0 and 100 m and of the oxygen minimum.

in the observed value is almost the same as that in the saturated value. Therefore, it may be said that the greater part of the seasonal variation of oxygen content at the surface is caused by the seasonal variations of water temperature and salinity. Though other factors such as mixing, biological activity etc. may give influences on the seasonal variation of oxygen content, the effects seem to be comparatively small than that due to the temperature and salinity variations.

The minimum of dissolved oxygen content

Observations in deep layer have been made usually at the interval of 200 m depth. More closer depth intervals may be required to detect exactly the oxygen minimum. In this study, the lowest value among those observed during 10 years is regarded as the most probable value for the oxygen minimum, assuming that the annual variation of oxygen content may be negligible. The minimum content of oxygen and the depth at which the minimum appears are shown in Fig. 4. The content varies much geographically in a wider range between 0.6 and

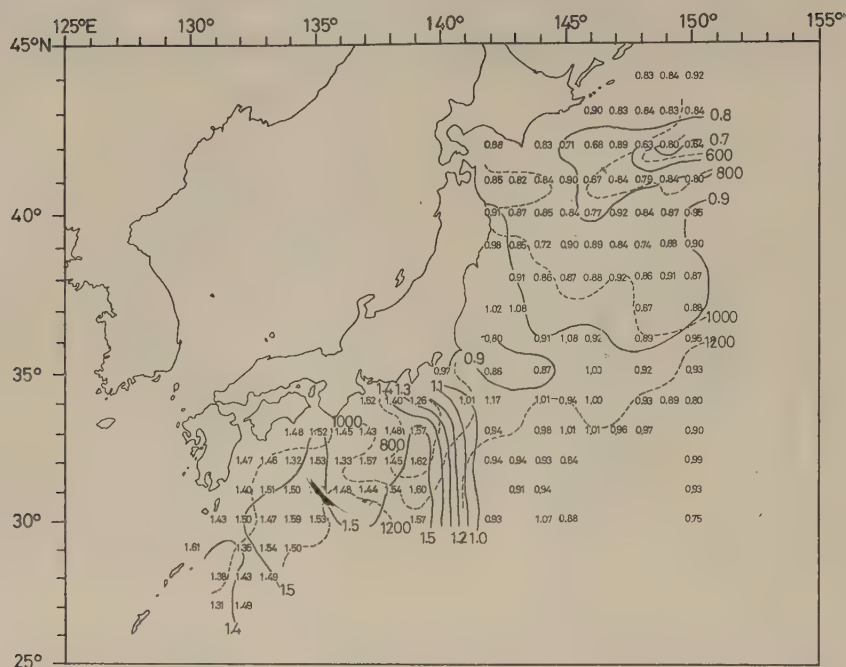
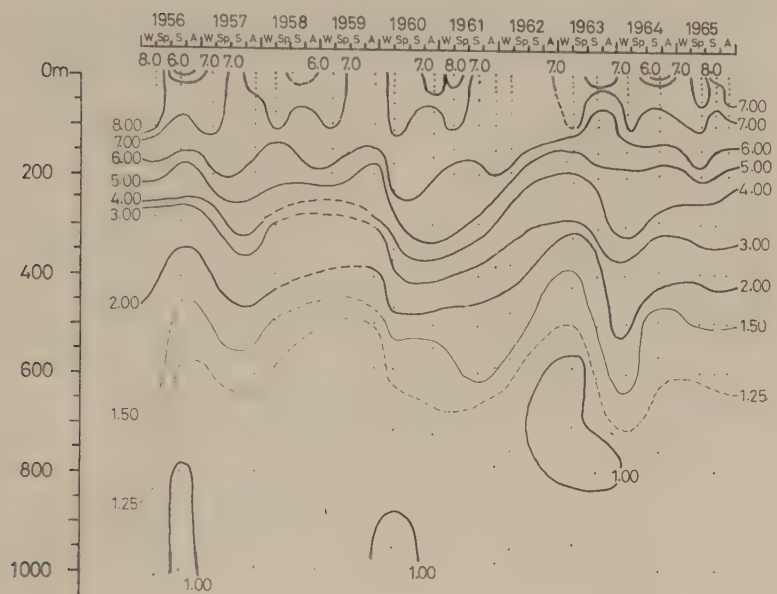


Fig. 4. The content of dissolved oxygen minimum (solid line) and the depth of its appearance (broken line).

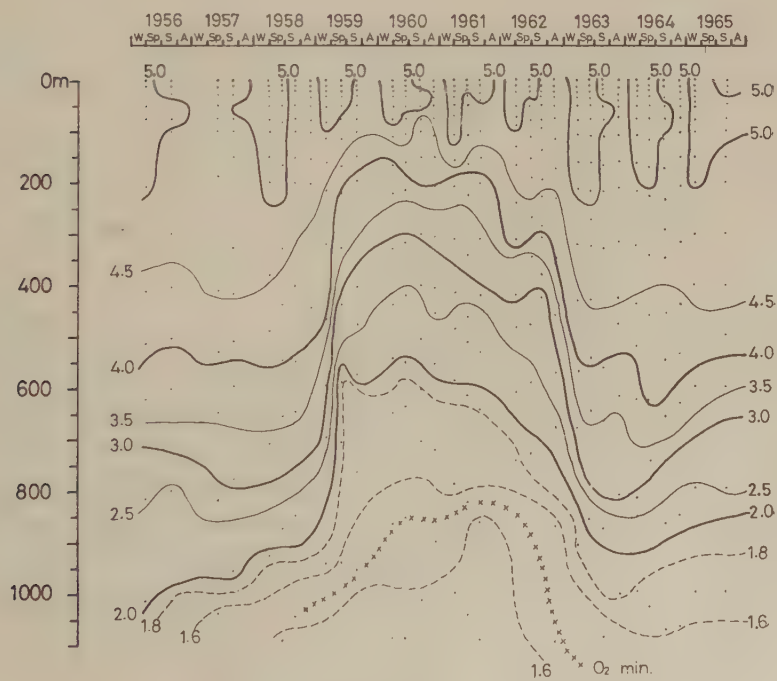
1.6 ml/l. A remarkable boundary was observed along the Izu-Ogasawara Ridge located at about 140°E. In the west of the boundary the content in oxygen is higher than 1.4 ml/l, while it is less than 1.0 ml/l in the east side. The content is generally low in the Oyashio region and becomes gradually larger as going towards the south. In the upwelling area located at 34°N, 138-139°E, the content is slightly less than that in the surrounding area.

The depth where the oxygen minimum is observed differs locally, shallower in the Oyashio region and deeper in the region south of the Kuroshio. It is found at the depth of only about 600 m in a region offshore branch of the Oyashio and it reaches down to 1,500 m at the deepest in the region south of the Kuroshio. The depth does not differ so much in the west and the east sides of the boundary where a large difference is observed in oxygen content. The density (σ_t) of sea water at the depth of oxygen minimum is between 27.25 and 27.50. It differs locally, being less than 27.40 in the west and higher than that in the east of the boundary. It is noticed that rather low density of 27.30 is observed in the Oyashio water.

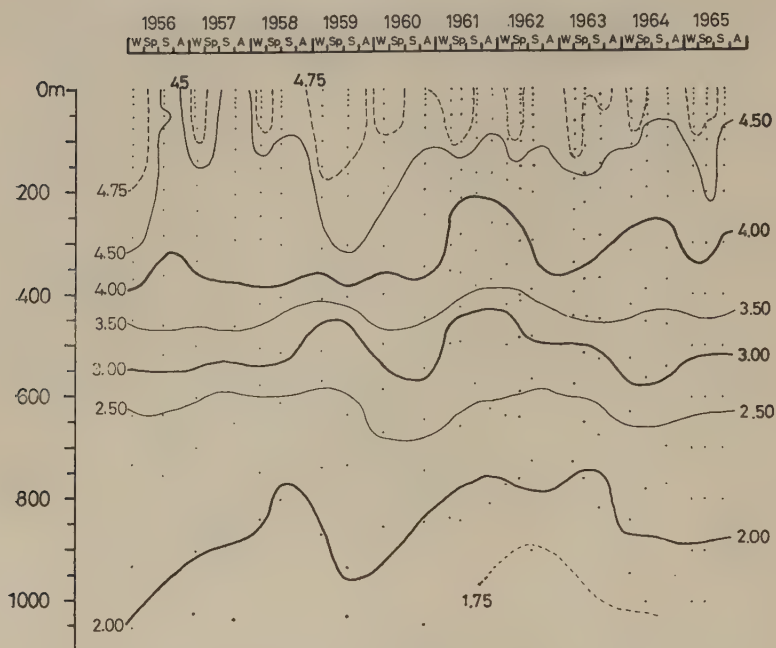
T. Akiyama: The Distribution of Dissolved Oxygen and Phosphate Phosphorus



5-1



5-2



5-3

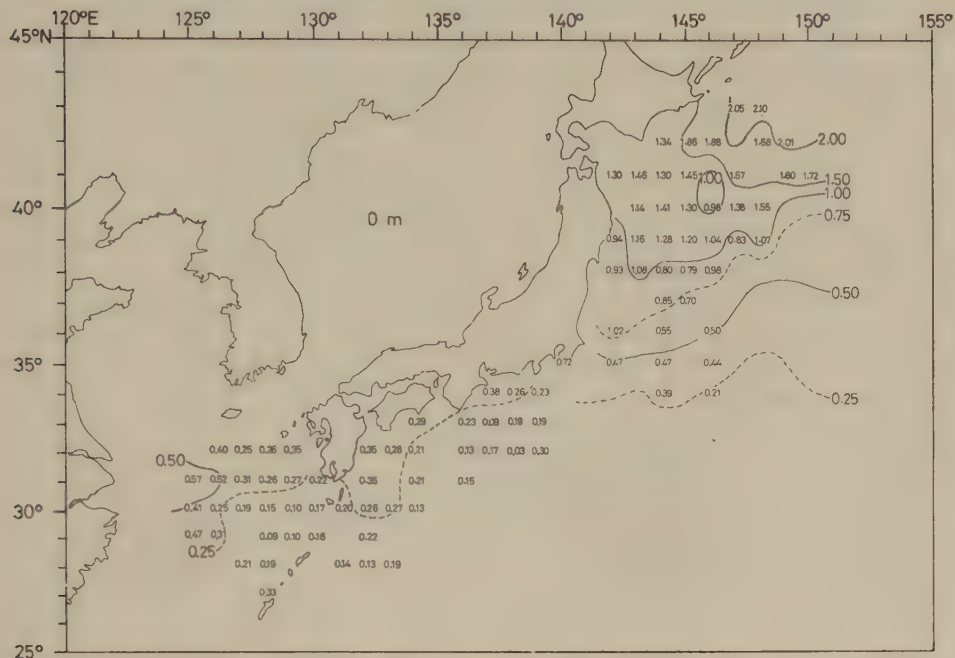
Fig. 5. Isopleth of dissolved oxygen content from 1956 to 1965 at locations of 41°N , 144°E (5-1), 32°N , 136°E (5-2) and 28°N , 127°E (5-3).

Comparing the contents of oxygen minimum in winter and summer, a little difference is found regionally. In most of areas they are slightly higher in winter, while in some limited areas are lower in winter.

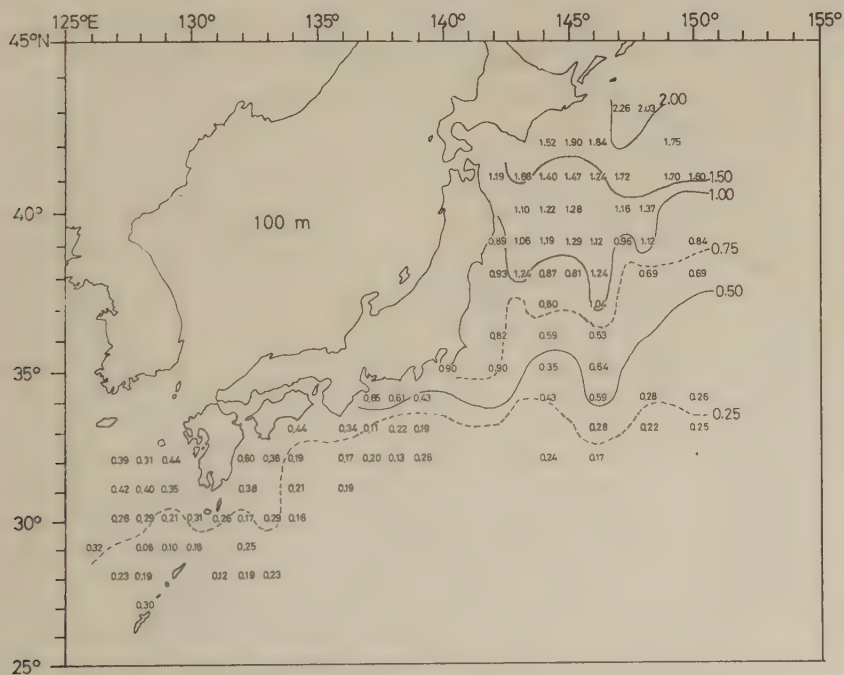
Annual variations in dissolved oxygen content

At some locations in the Kuroshio and the Oyashio where the large number of data are available, the annual variation is examined. At a location of 32°N , 136°E , the annual variation is notable probably due to the drift of the Kuroshio in latitudinal direction. The Kuroshio flowed south of the location in the years from 1959 to 1962, therefore the location was situated in the upwelling area during the period. Thus the alternation of water masses may have taken place often at the location near the boundary zone. No remarkable annual variation is found at other locations, 28°N , 127°E and 41°N , 144°E as the above site.

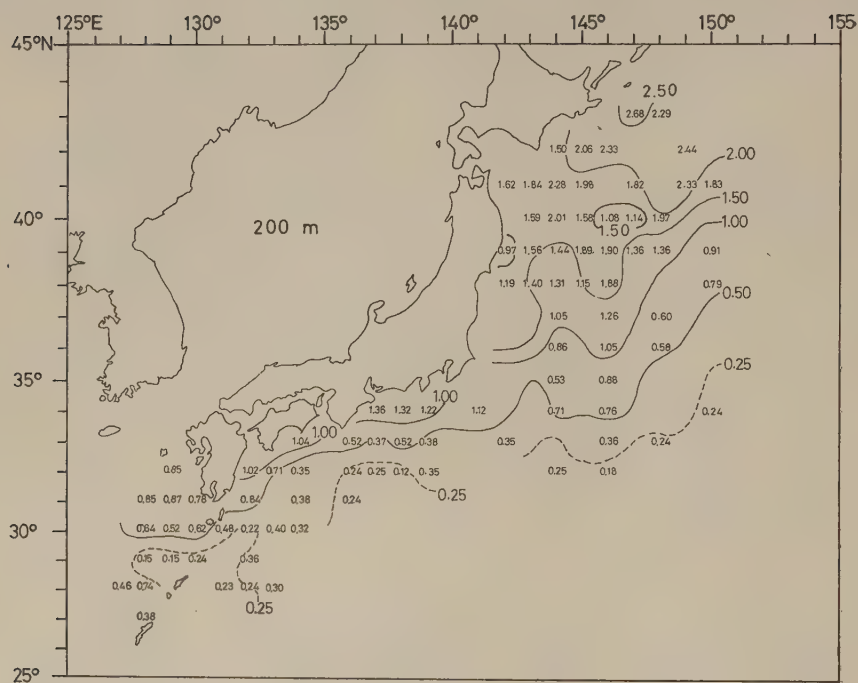
T. Akiyama: The Distribution of Dissolved Oxygen and Phosphate Phosphorus



6-a-1



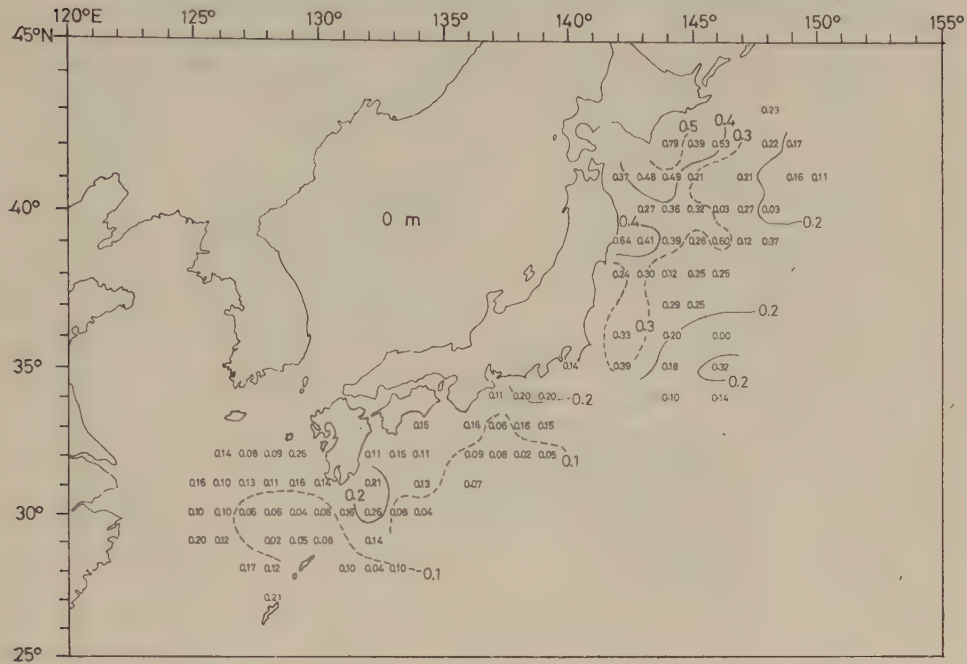
6-a-2



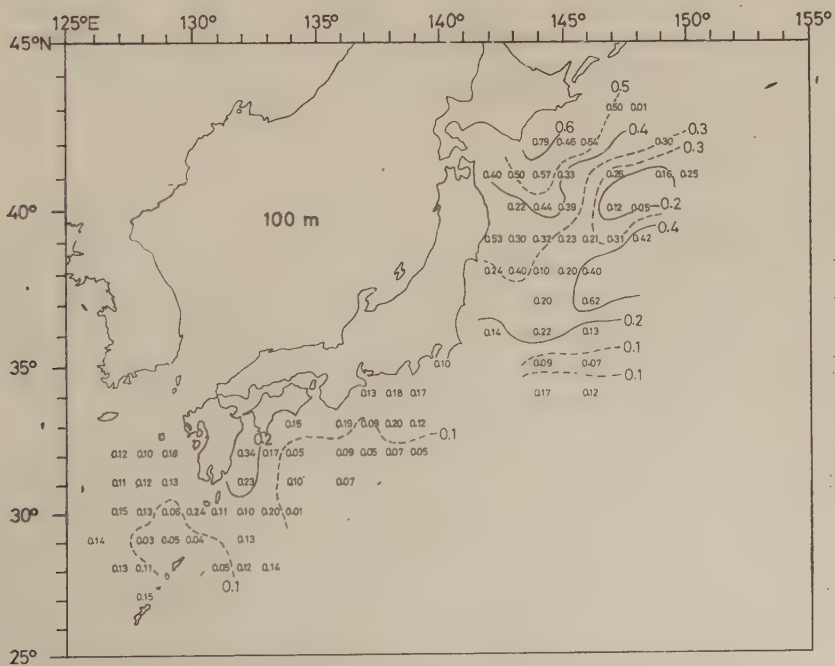
6-a-3

Fig. 6-a. Annual mean values of phosphate phosphorus content in winter ($\mu\text{g-atoms/l}$).

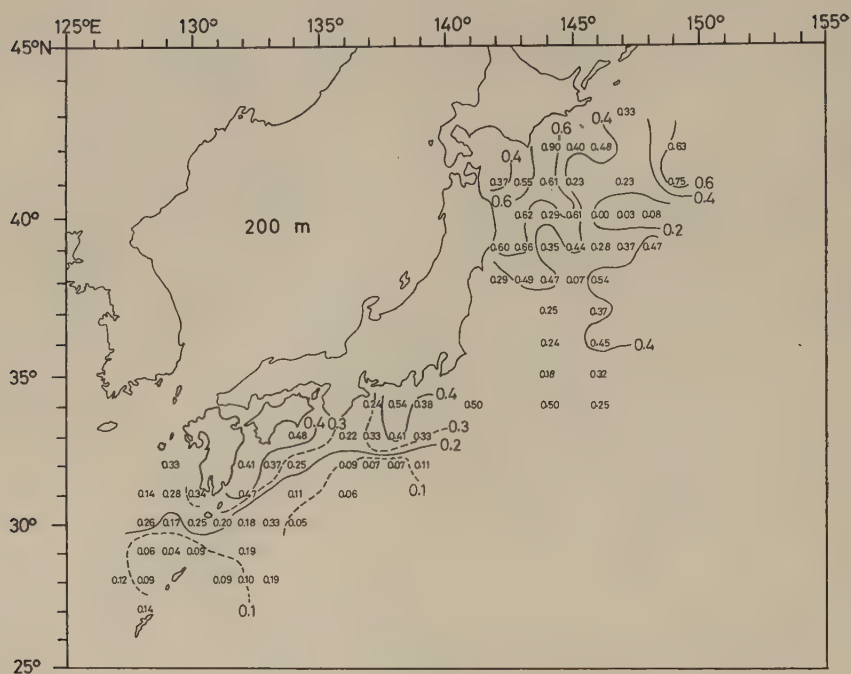
T. Akiyama: The Distribution of Dissolved Oxygen and Phosphate Phosphorus



6-b-1



6-b-2



6-b-3

Fig. 6-b. Standard deviations from annual mean values in Fig. 6-a.

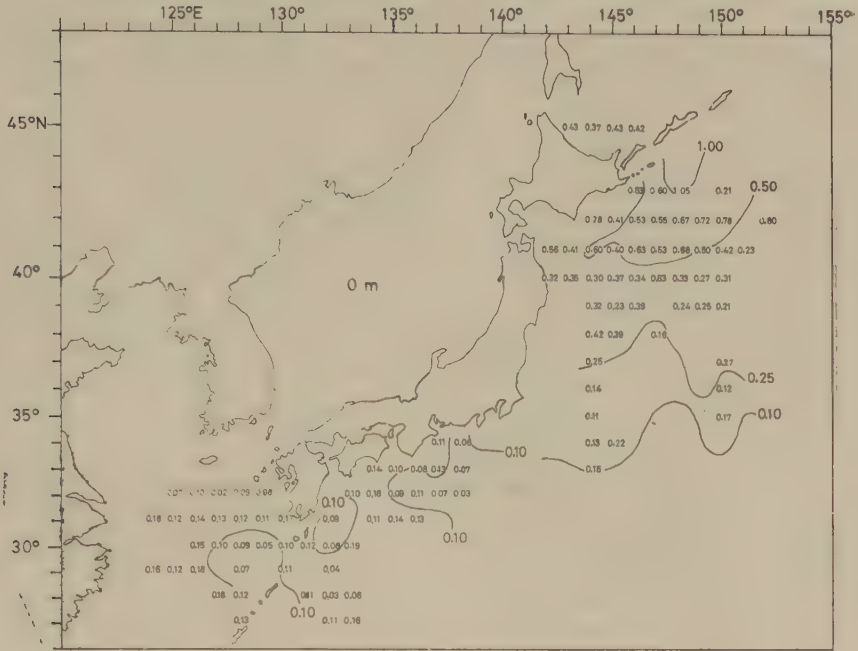
3-2. Phosphate phosphorus

General features of distribution

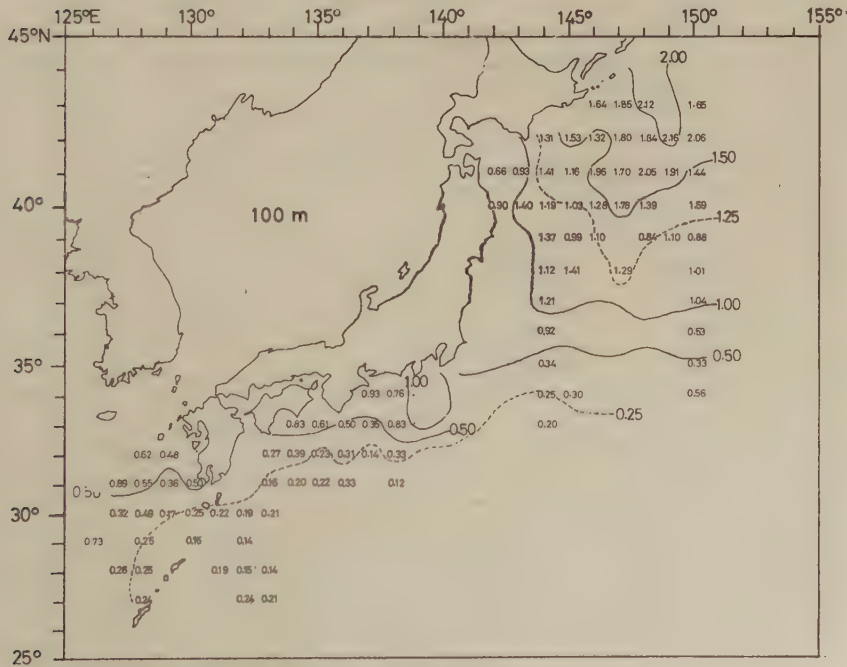
The available data of phosphate phosphorus up to present are less and discontinuous in space and time than dissolved oxygen. To make a statistical assessment numbers of data may not be enough especially in the region east of Honshu, Japan. Hence in order to get the reliable feature on the general distribution of phosphorus the further accumulation of data will be needed.

As is well known, the mean content of phosphate phosphorus is low in the Kuroshio, high in the Oyashio and intermediate in the mixing zone. Estimations of the contents in various water masses are approximately given in Table 3. The content in surface water of the Kuroshio increases by 0.3-0.4 $\mu\text{g-atoms/l}$ in winter as the Kuroshio proceeds eastwards, but little increase is found in summer. In the Oyashio region rather high content is observed in the offshore branch than in the coastal branch, being contrary to the case of dissolved oxygen. In

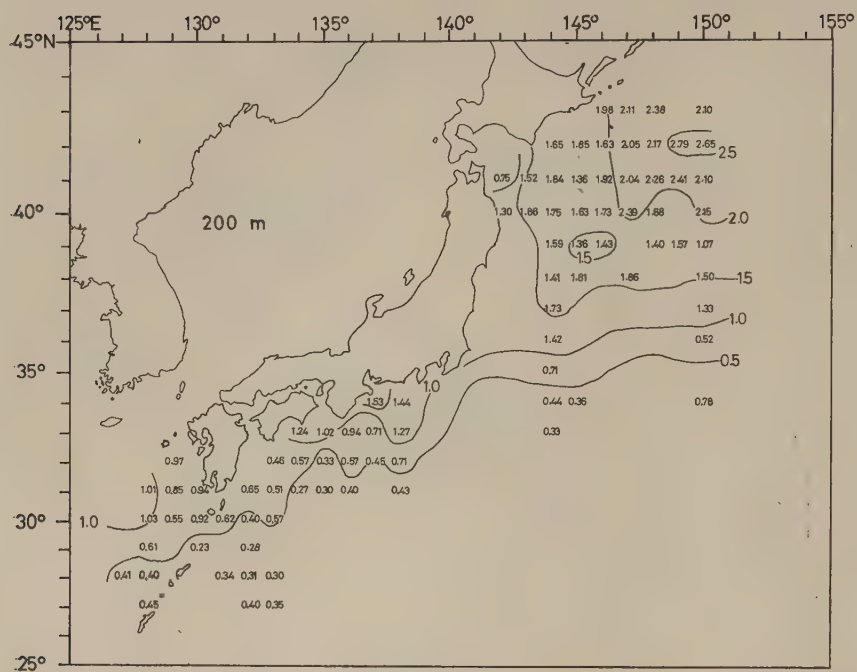
T. Akiyama: The Distribution of Dissolved Oxygen and Phosphate Phosphorus



7-a-1



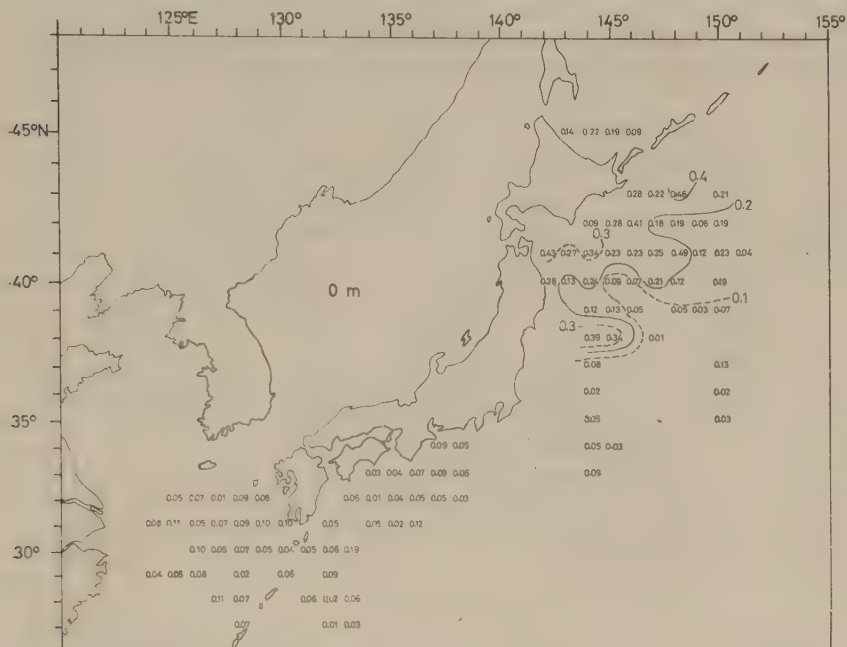
7-a-2



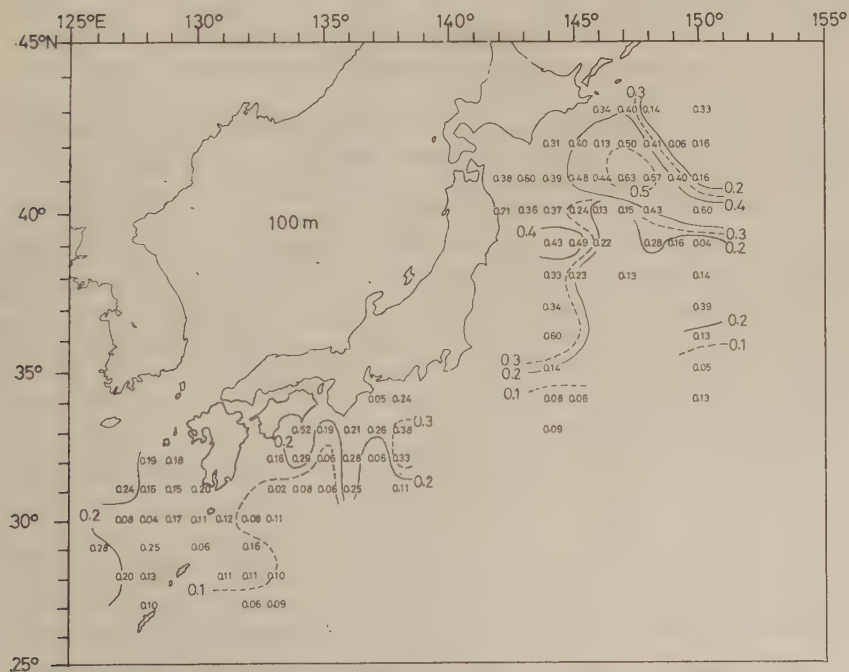
7-a-3

Fig. 7-a. Annual mean values of phosphate phosphorus content in summer ($\mu\text{g-atoms/l}$).

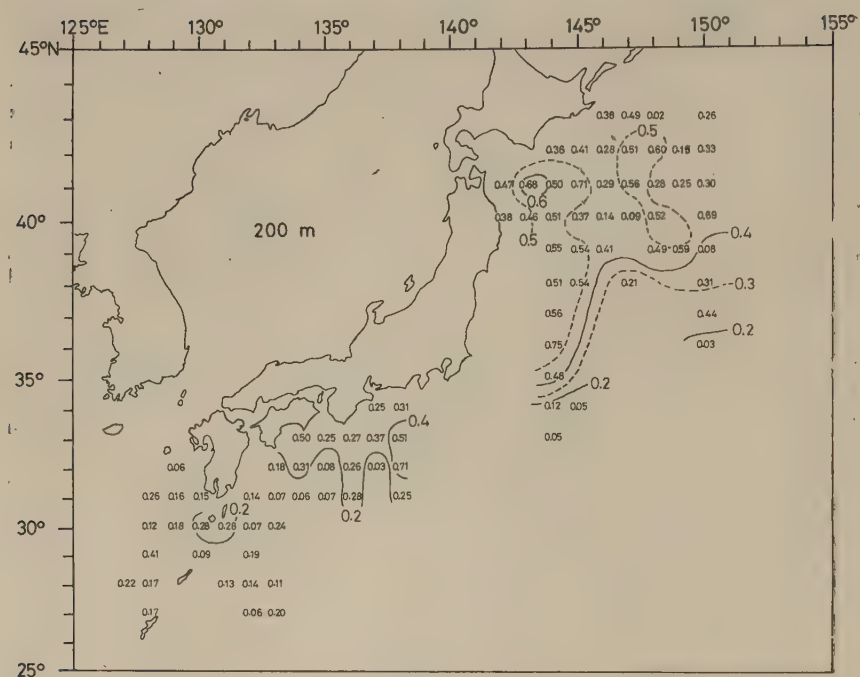
T. Akiyama: The Distribution of Dissolved Oxygen and Phosphate Phosphorus



7-b-1



7-b-2



7-b-3

Fig. 7-b. Standard deviations from annual mean values in Fig. 7-a.

Table 3. Estimations of annual mean contents of phosphate phosphorus in various water masses around Japan ($\mu\text{g-atoms/l}$).

In Winter							
Standard depth (m)	Kuroshio		Oyashio		Tsushima W.C. west of Kyushu	Yellow Sea	Coastal W. south of Honshu
	(130° E)	(150° E)	coastal	offshore			
0	0.1	0.4	1.5	2.0	0.3	0.5	0.3
100	0.2	0.4	1.5	2.0	0.4	—	0.5
200	0.2	0.6	1.5	2.5	0.8	—	1.3
In Summer							
0	0.1	0.2	0.5	0.7	0.1	0.2	0.1
100	0.2	0.3	0.9	2.0	0.5	—	0.8
200	0.4	0.5	1.5	2.5	0.8	—	1.5

waters of the Tsushima Warm Current west of Kyushu and coastal area south of Honshu phosphorus contents are a little higher than in the Kuroshio. The

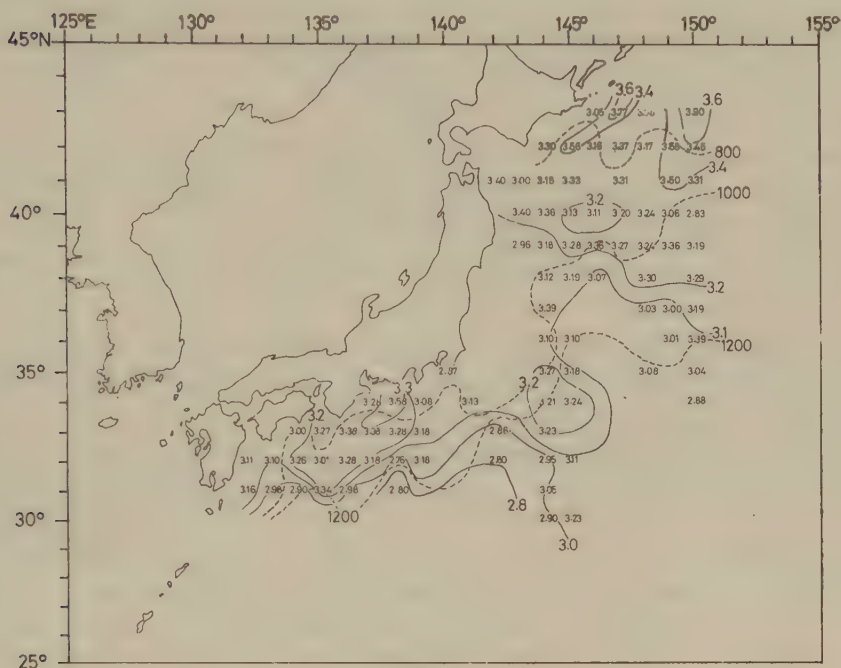


Fig. 8. The content of phosphate phosphorus maximum (solid line) and the depth of its appearance (broken line).

vertical gradient in the surface layer is small in winter, while it is fairly large in summer especially in the Oyashio region.

Seasonal difference of the phosphate contents between winter and summer is large as much as $1.0 \mu\text{g-atoms/l}$ in the upper 100 m layer of the Oyashio region. However, the difference is no longer found at the depth of 200 m where the photosynthetic activity is weak. The difference may be attributed to the biological utilization of phosphorus by assimilation. In regions other than the Oyashio the seasonal differences are comparatively small (about $0.3 \mu\text{g-atoms/l}$). Phosphorus may be more useful than the dissolved oxygen to study the biological effect in the surface layer of the ocean, because there is the exchange of oxygen between the air and the ocean surface.

Standard deviations of phosphorus content

Standard deviations give the degree of the annual variation at each location. The standard deviation in the surface layer is less than $0.1 \mu\text{g-atoms/l}$ in the Kuroshio and is high as much as $0.5 \mu\text{g-atoms/l}$ in the coastal branch of the

Oyashio. Relatively low standard deviations less than $0.2 \mu\text{g-atoms/l}$ are found at the shallower layer than 100 m in the offshore branch of the Oyashio.

The maximum of phosphate phosphorus content

The maximum content of phosphate phosphorus on the vertical direction and the depth of its appearance are shown in Fig. 8. The contents is distributed in the range between 2.8 and $3.8 \mu\text{g-atoms/l}$.

Higher values more than $3.5 \mu\text{g-atoms/l}$ are found in region of the offshore branch of the Oyashio and in upwelling area located at 34°N , 138°E . Lower values less than $3.0 \mu\text{g-atoms/l}$ are found in region south of the Kuroshio.

The depth at which phosphate maximum appears ranging from 600 to 1,500 m almost coincides with that of the oxygen minimum.

The boundary along the Izu-Ogasawara Ridge which is observed in the oxygen minimum distribution is not clearly found in the case of phosphorus.

Acknowledgements: The author wishes his best thank to Prof. Yasuo MIYAKE, Tokyo Kyoiku University, for his kind advice and proof reading of the manuscript. He also appreciates to Mr. K. KIMURA for his assistance in preparing the data.

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Second Cruise for CSK, *Ryofu Maru*, January to March 1968

By

Jotaro MASUZAWA

Japan Meteorological Agency

(Received October 31, 1968)

The second cruise for the Cooperative Study of the Kureshio and Adjacent Regions (CSK) was made in January to March 1968 east of the Philippines by the R. V. *Ryofu Maru* of the Japan Meteorological Agency (JMA). The survey consists of four long meridional sections at 137°E, 133°30'E, 130°E and 127°E and two short sections, the one between Mindanao and Halmahera and the other east of Mindanao (Fig. 1).

1. Itinerary

Port	Arrival	Departure
Tokyo, Japan	—	January 13
Cebu, Philippines	February 1	February 5
Naha, Okinawa	February 21	February 25
Keelung, Taiwan	March 13	March 18
Tokyo, Japan	March 22	—

2. Personnel

Captain	K. SHIRAKAWA
Scientists	
Chief	J. MASUZAWA, Marine Division, JMA
Phys. oceanography	H. AKAMATSU, ,,
	T. SAWARA, ,,
	I. FUJIWARA, ,,
	T. URASHIMA, ,,
	K. HATA, Hakodate Marine Observatory
	S. KONAGA, Kobe Marine Observatory

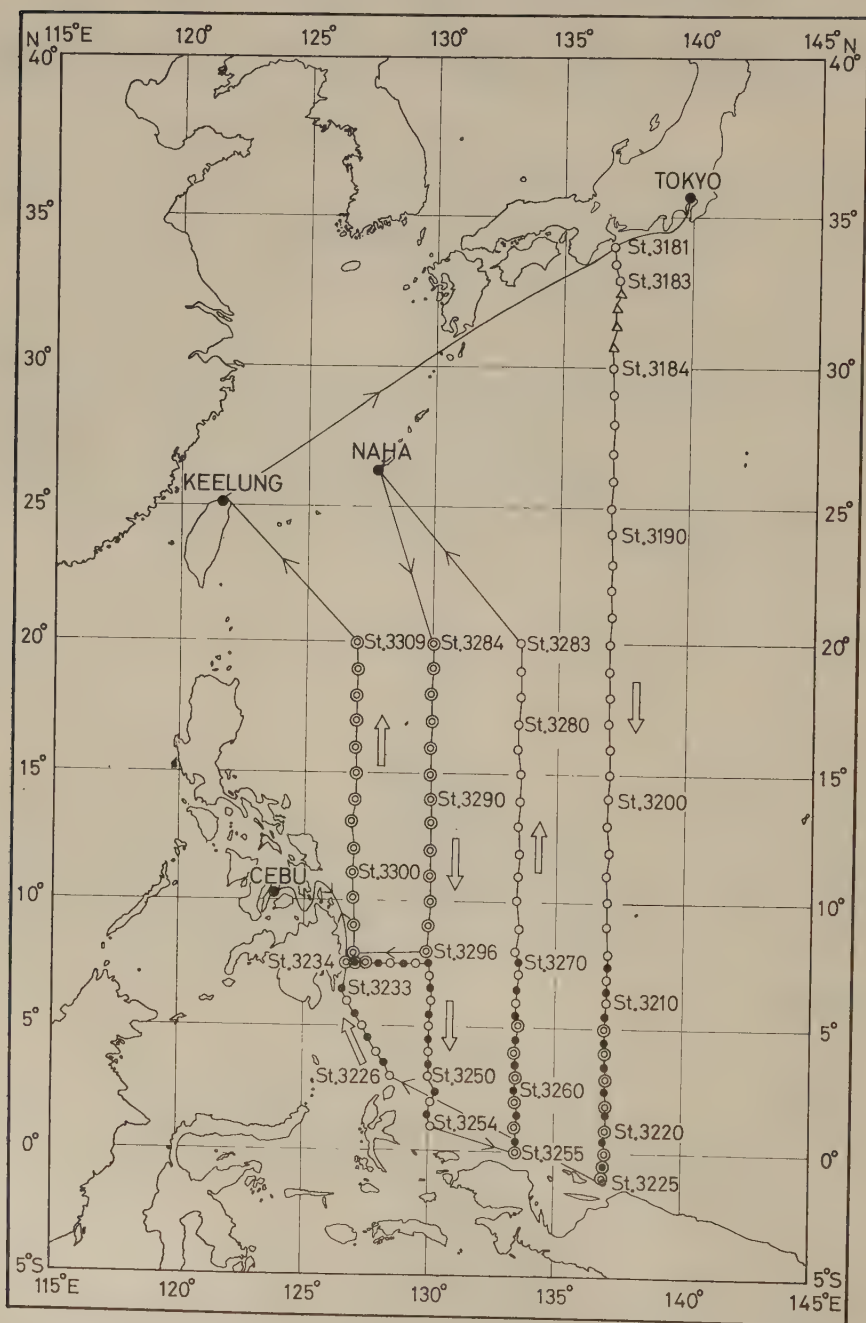


Fig. 1. Track chart of the second cruise for the CSK made by the *Ryofu Maru* of the JMA in January to March 1968. The open circle, double circle and dot indicate the deep station, current-measurement station and shallow station, respectively.

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Meteorology	S. HAYASHI, Marine Division, JMA
	I. MIYASHITA, „
	I. FUJITA, „
Chemistry	C. P. ALACANCES, Jr., Philippines Weather Bureau
	T. AKIYAMA, Marine Division, JMA
	H. YOSHIMURA, „
	T. SAGI, „
	T. YURA, „
Planktology	Y. KAWARADA, Marine Division, JMA
	A. SANO, „
	T. OGAWA, Maizuru Marine Observatory
	M. MATSUZAKI, Nagasaki Marine Observatory

3. Sampling

Ninety-seven stations for hydrographic casts deeper than 1,000 m were made at intervals of 60 miles on the prearranged lines. In addition, thirty-one shallow stations (less than 400 m) were taken at the middle between two adjacent deep-stations south of 8°N. The sampling depth was chosen as listed below,

North of 20°N: 50, 100, 150, 200, 300, 400, 500, 600, 700, 800, 900, 1,000 m, ...

8°N-20°N: 25, 50, 75, 100, 125, 150, 175, 200, 250, 300, 350, 400, 500, 600,
700, 800, 900, 1,000 m, ...

south of 8°N: 25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275, 300, 350, 400,
500, 600, 800, 1,000 m, ...

BT lowerings were made at each hydrographic station, and current measurements in the upper 400 m were made at 43 stations in Fig. 1 by the current-meter 'Type T-S II.' Ordinary meteorological observations were done every three hours, and measurements of clouds by meteorological rader, of winds by ultra-sonic anemograph, and of radiation from sky and sea, and aerological observations were sometimes made in the equatorial region. And also the content of carbon-dioxid in the air was continuously recorded.

Chemical elements determined on board are salinity (128 sts.), oxygen (128 sts.), phosphate-P (97 sts.), silicate-Si (97 sts.), nitrate-N (30 sts.), nitrite-N (32 sts.), ammonia-N (32 sts.), and carbon-dioxid in surface water (43 sts.). The water was sampled from the sea surface and subsurface depths for the determination of total-P (72 sts.), calcium (91 sts.), trace metals (11 sts.), chlorinity by gravimetry (6 sts.) and gross β radio activity (12 sts.).

The Norpac net (GG 54, 0.33 mm mesh) was hauled vertically from the estimated depth of 150 m at 126 stations for the standard sampling of zooplankton and the Norpac net (XX 13, 0.095 mm mesh) at 64 stations for the microplankton sampling. One-liter surface water was sampled at 133 stations for the quantitative determination of microplankton. For the study on the vertical distribution of zooplankton, the vertical haulings with the automatic opening-and-closing multiple net were made from those four layers (0-250 m, 250-500 m, 500-750 m, 750-1,000 m) at 16 stations, and sample water was drawn from Nansen bottles at 14 depths in the upper 300 m at 25 stations.

4. Results

1) *The long meridional section at 137°E*

The long meridional section at 137°E from Japan to New Guinea was made again from the 14th to the 27th January 1968 in the similar way as was done from the 12th to the 24th January 1967 during the first cruise for the CSK (MASUZAWA, 1967 a, b). Thus, differences can be seen in the oceanographic conditions of the western North Pacific between two winters. The measurement of the Kuroshio just south of Japan was missed because we had rough weather unfortunately.

Fig. 2 shows the temperature, salinity and geopotential anomaly relative to 1,000 db at the sea surface in two winters. The surface water north of 25°N is lower in temperature and higher in salinity in 1968 than in 1967. This may be caused by the larger evaporation from the sea surface due to the stronger monsoon in 1968.

In the North Equatorial Current between 20°N and 7°N, on the other hand, both the temperature and salinity are lower in 1968 than in 1967. This could be related to the smaller transport of water which is higher in both temperature and salinity from the east by the North Equatorial Current.

The largest slope of the sea surface in the North Equatorial Current is found near 15.5°N in 1968, while near 13.5°N in 1967. Likewise, the southern limit of the North Equatorial Current is located rather north in 1968 than in 1967. Incidentally, the salinity minimum near the southern limit of the North Equatorial Current lies further north in 1968 than in 1967. The geostrophic flux relative to 600 db by the northern half (20°N to 15°N) of the North Equatorial Current (20°N to 7°N) amounts to 68% (102 km³/hr) of the total flux (150 km³/hr),

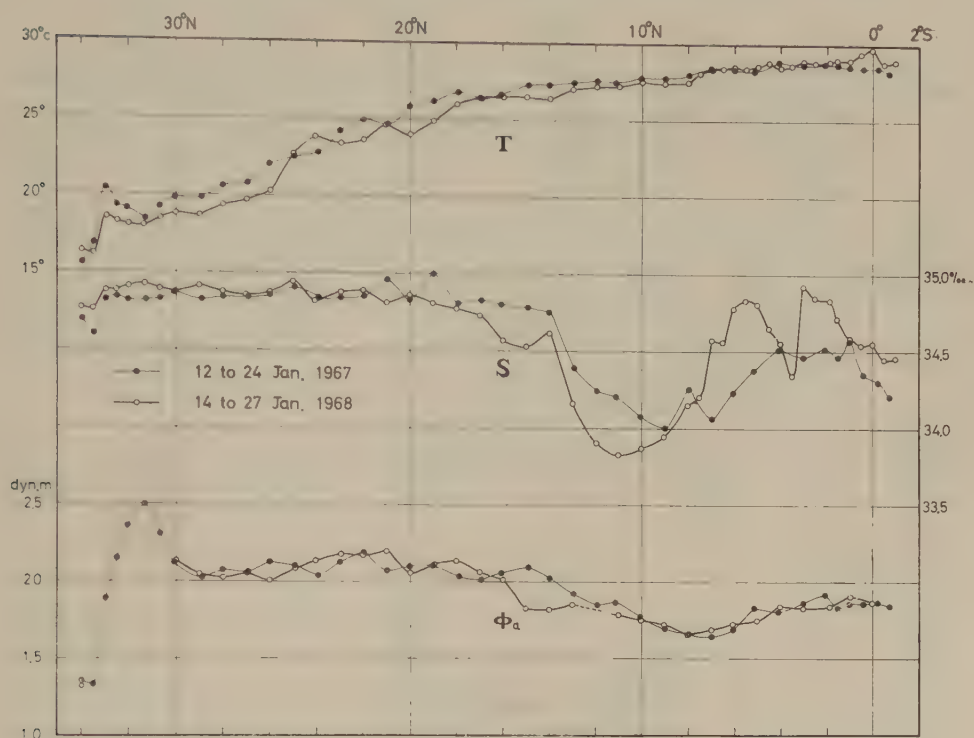


Fig. 2. Profiles of temperature (T), salinity (S) and geopotential anomaly (ϕ_a) relative to 1,000 db at the sea surface at 137°E in January, 1967 and 1968.

in 1968, though it is only 20% ($35 \text{ km}^3/\text{hr}$) of the total ($178 \text{ km}^3/\text{hr}$) in 1967. Those results suggest that the North Equatorial Current was rather north in 1968 than in 1967.

It is noted that the salinity in the equatorial region south of 7°N is remarkably higher in 1968. This might be associated with the stronger intrusion of the saline South Tropical Water (CANNON, 1966) into the North Pacific in 1968.

2) Equatorial currents north of Western New Guinea

Current measurements were made from the drifting ship south of 5°N at 133°30'E and 137°E with two currentmeters, one of them being placed at a depth of 600 m to 900 m to estimate ship drift (Fig. 3).

Eastward currents (about 1 kt) in the upper 200 m at 4°N and 5°N in both sections are the Equatorial Countercurrent. The eastward currents in depths of

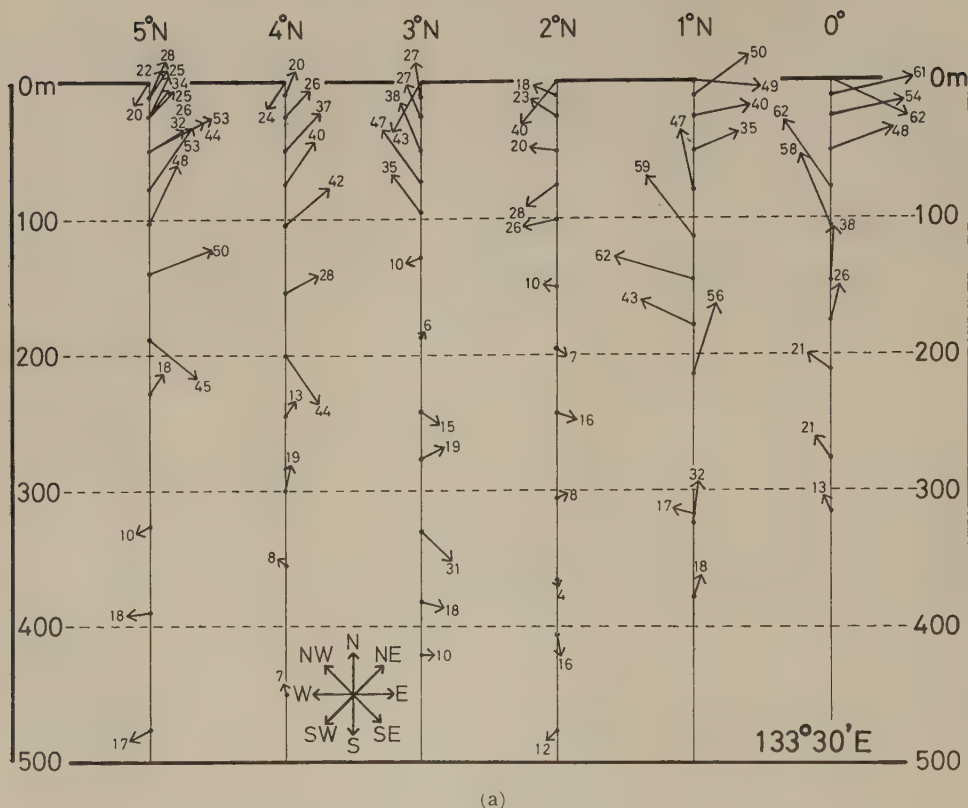
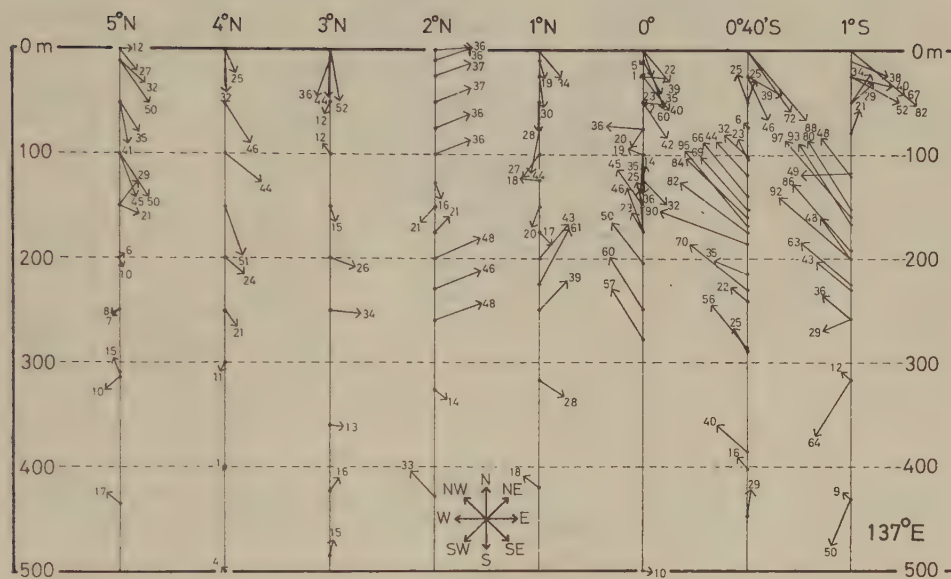


Fig. 3. Vertical distributions of velocities in cm/sec measured relative to a depth

200 to 300 m at 1°N and 2°N in the 137°E section seem to be the beginning of the Equatorial Undercurrent. Similar eastward currents near the equator were observed in 1967, though the speed is about 1 kt in 1968 and about 3 kt in 1967 (MASUZAWA, 1967 b).

Near the equator the westward South Equatorial Current as high as 2 kt was found in the 100-300 m layer. The South Equatorial Current at 137°E is higher in speed and wider in 1968, though the Current is covered by the shallow eastward flow of the New Guinea Coastal Current in 1968 like in 1967.

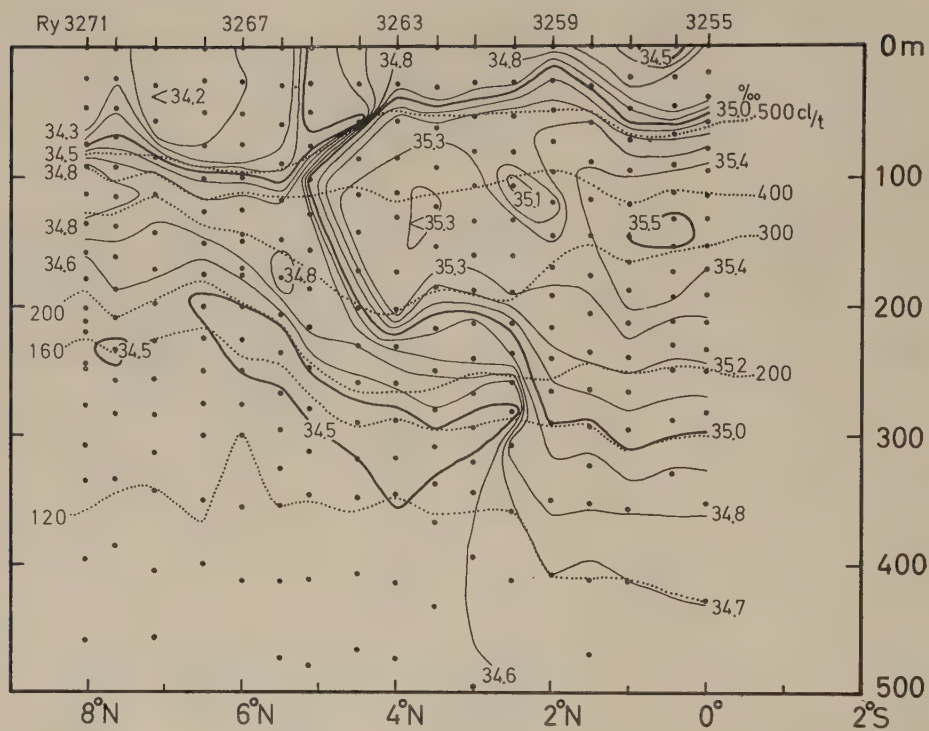
The South Equatorial Current carries the saline Tropical Water from the South Pacific to the north of New Guinea (Fig. 4 b). The Tropical Water from the South Pacific near the equator at 137°E is higher in salinity and larger in volume of the most saline water exceeding 35.5‰ in 1968 than in 1967. The



(b)

of 600 m to 900 m in the equatorial region (a) at $133^{\circ}30'E$ and (b) at $137^{\circ}E$.

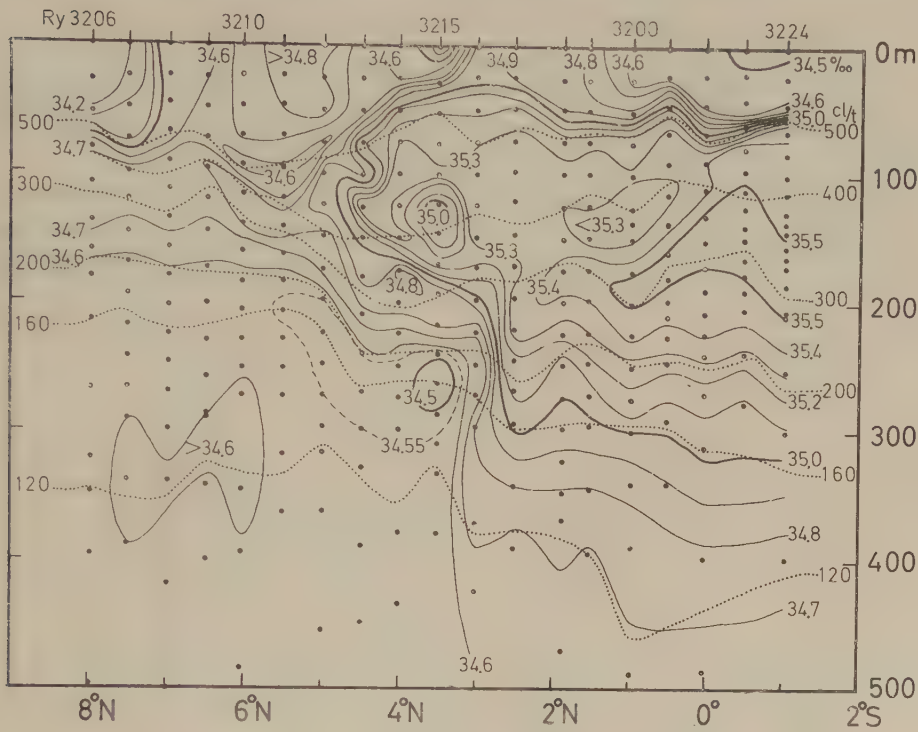
low-salinity water is found in depths of 100 m to 150 m at $2^{\circ}N$, $133^{\circ}30'E$ and at $3^{\circ}30'N$, $137^{\circ}E$ (Fig. 4). These characteristic waters lie near the 400 cl/t isanosteric surface in the South Tropical Water and they may be of the North Pacific origin. A similar small watermass was observed in the $137^{\circ}E$ section in 1967 (MASUZAWA, 1967 b).



(a)

Fig. 4. The salinity section south of 8°N

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(a) at 133°30'E and (b) at 137°E.

3) Mindanao Current

A cyclonic eddy was seen east of Mindanao, which was called the Mindanao Eddy by WYRTKI (1961) (Fig. 5). A section at $7^{\circ}30'N$ was made to measure the Mindanao Current close to the coast of Mindanao.

The Mindanao Current flowed nearly due south in the narrow coastal zone with the width of 30 miles or so. The maximum speed measured by the current-meter is as high as 3 kt, referred to the velocity at 600 m depth (Fig. 6). The

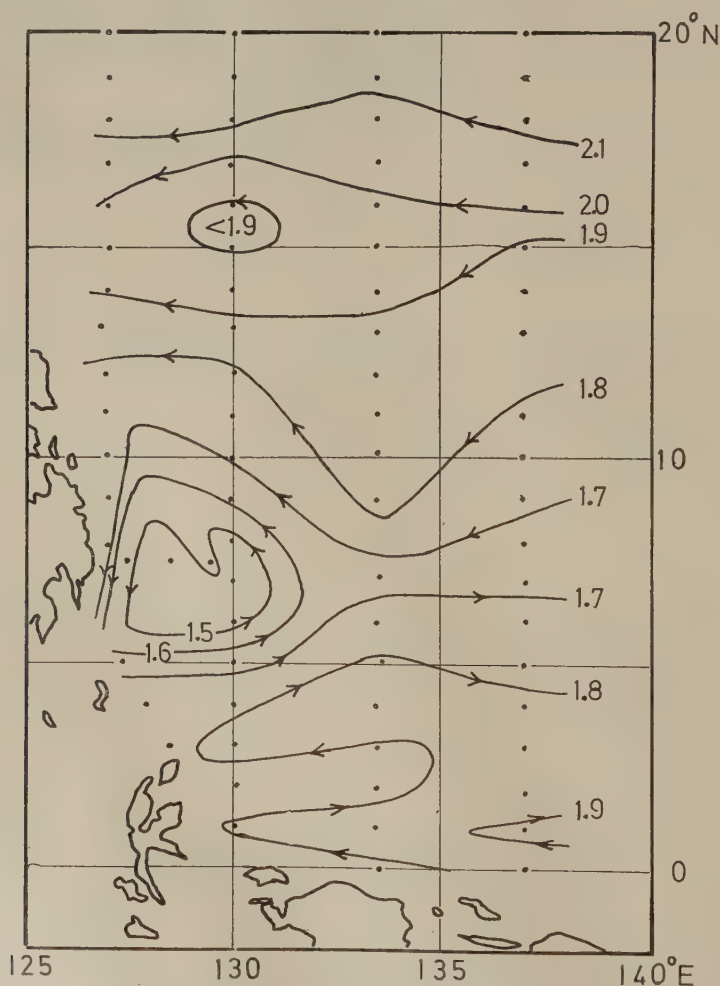


Fig. 5. Geopotential topography at the sea surface relative to 1,000 db, the contour interval is 10 dynamic centimeter.

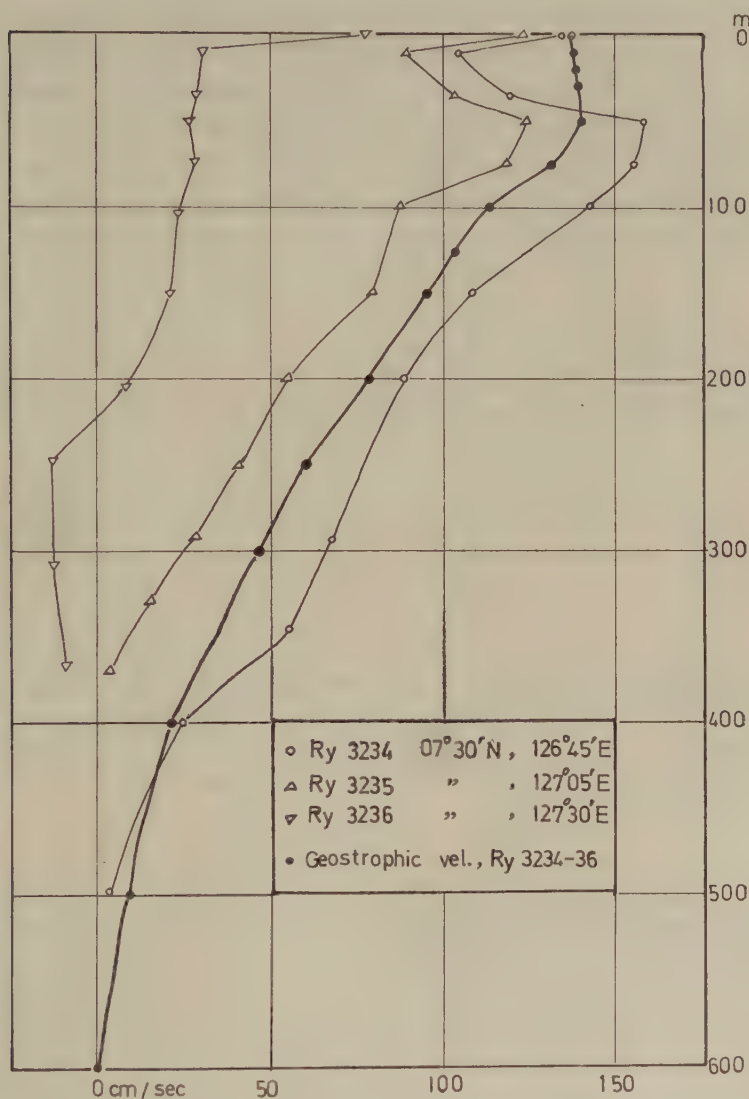


Fig. 6. Vertical distributions of the measured and computed speeds relative to 600 db in the Mindanao Current at 7°30' N.

geostrophic speed relative to 600 db between the first station (Ry 3234) and the third station (Ry 3236) from the coast roughly equals to the average speed measured between the first and second stations. The geostrophic velocities of the Mindanao Current were 2 or 3 kt in the two sections made by the *Atlantis II* in

August 1965 (CANNON, in press). The geostrophic flux over 600 m depth is as much as $104 \text{ km}^3/\text{hr}$. The true flux by the Mindanao Current is likely to be much larger than the value computed here, which includes neither the flux between the coast and the first station nor the flux below 600 m.

The Mindanao Current carries the characteristic waters from the middle or northern part of the North Equatorial Current, such as the saline North Tropical Water and the less saline North Pacific Intermediate Water (Fig. 7).

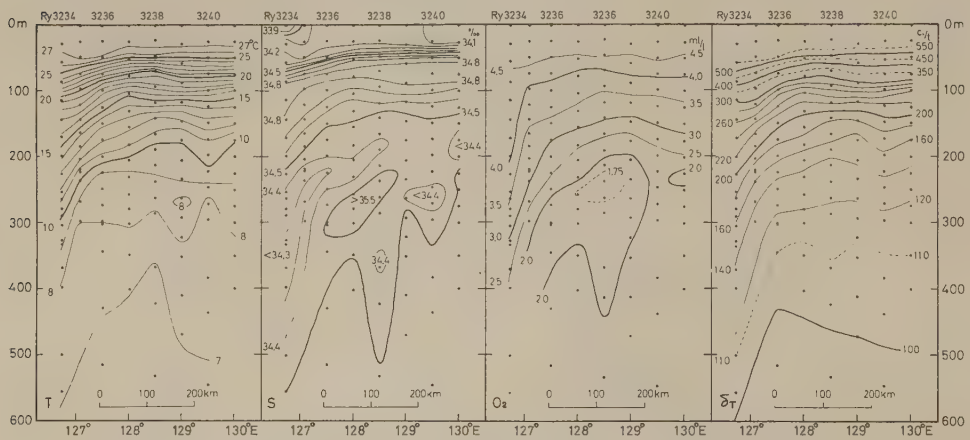


Fig. 7. Vertical sections of temperature, salinity, oxygen and thermocline anomaly across the Mindanao Current at $7^{\circ}30' \text{ N}$.

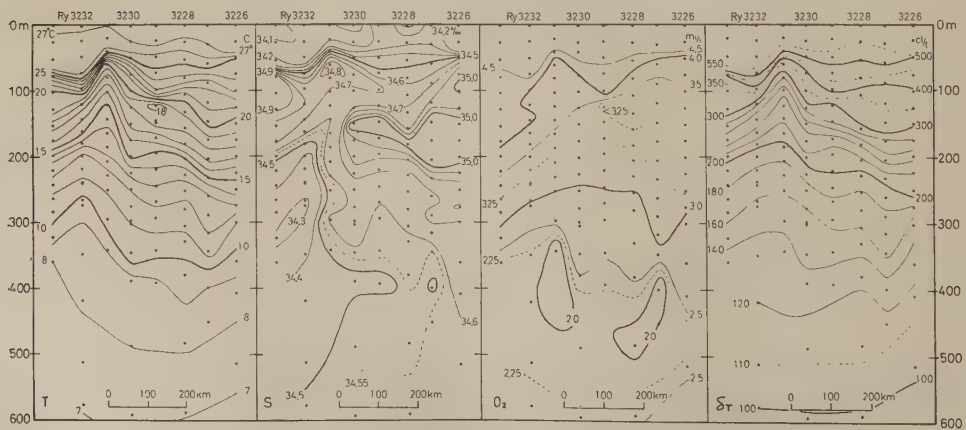


Fig. 8. Vertical sections of temperature, salinity, oxygen and thermocline anomaly between Mindanao and Halmahera.

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The section between Mindanao and Halmahera (Fig. 8) suggests that most or part of the Mindanao Current crosses the northern part of the section, between the southern tip of Mindanao and Talaud Island, and there is an eastward flow across the southern half of the section. In the northern part there are the North Tropical Water and the North Pacific Intermediate Water as seen in the Mindanao Current at 7°30'N. On the other hand, the saline water of the South Pacific origin lies in depths of 150 to 200 m in the southern half of the section. Thus, two separate maxima of salinity are found in the middle part of the section. Part of waters in the section may come from Molucca Passage.

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Distribution of Plankton in the Waters neighboring Japan in 1966 (CSK)

By

Y. KAWARADA, M. KITOU, K. FURUHASHI and A. SANO
Japan Meteorological Agency

(Received December 15, 1968)

1. Introduction

The plankton samples were collected by the research vessels of the Japan Meteorological Agency, during their CSK (Cooperative Study of the Kuroshio and Adjacent Regions) Cruises in the waters neighboring Japan from January to March and July to October 1966. The materials were obtained by the Chofu Maru of the Nagasaki Marine Observatory in the East China Sea and off the east coast of Taiwan, by the Shumpu Maru of the Kobe Marine Observatory off the south coast of Japan, by the Ryofu Maru of the Marine Division, Japan Meteorological Agency and by the Kofu Maru of the Hakodate Marine Observatory off the east coast of Japan, and by the Seifu Maru of the Maizuru Marine Observatory in the Japan Sea. In addition, samplings were made also in the Okhotsk Sea by the Kofu Maru in the summer. The sampling positions on these cruises were not so different from those in 1965 (AKAMATSU and SAWARA, 1966, 1967; KAWARADA *et al.*, 1966).

For collecting the surface microplankton and the macroplankton in the surface layer, the standard methods which are detailed in the previous paper (KAWARADA *et al.*, *loc. cit.*) were employed; shortly microplankton samples contained in 500 ml of surface water are concentrated by decanting and later by centrifugalizing, and samplings of macroplankton are made by 150 m approximately vertical hauls with a Norpac net.

2. Distribution of surface microplankton

2-1 Winter (January-March, 1966) (Figs. 1, 2)

(1) Kuroshio

It seems that the population density of diatoms in the Kuroshio Water shows

a tendency to increase with proceeding to the west; the amounts of diatoms in the East China Sea and off the east coast of Taiwan are small, being 10^2 to 10^3 cells per liter of water, off the south coast of Japan are from 10^3 to 10^4 cells and off the east coast of Japan reach about $5 \cdot 10^4$ cells at several stations. Such distributional patterns of diatoms in the Kuroshio are in marked contrast to those in the winter of 1965 (KAWARADA *et al.*, *loc. cit.*). Moreover, it is notable

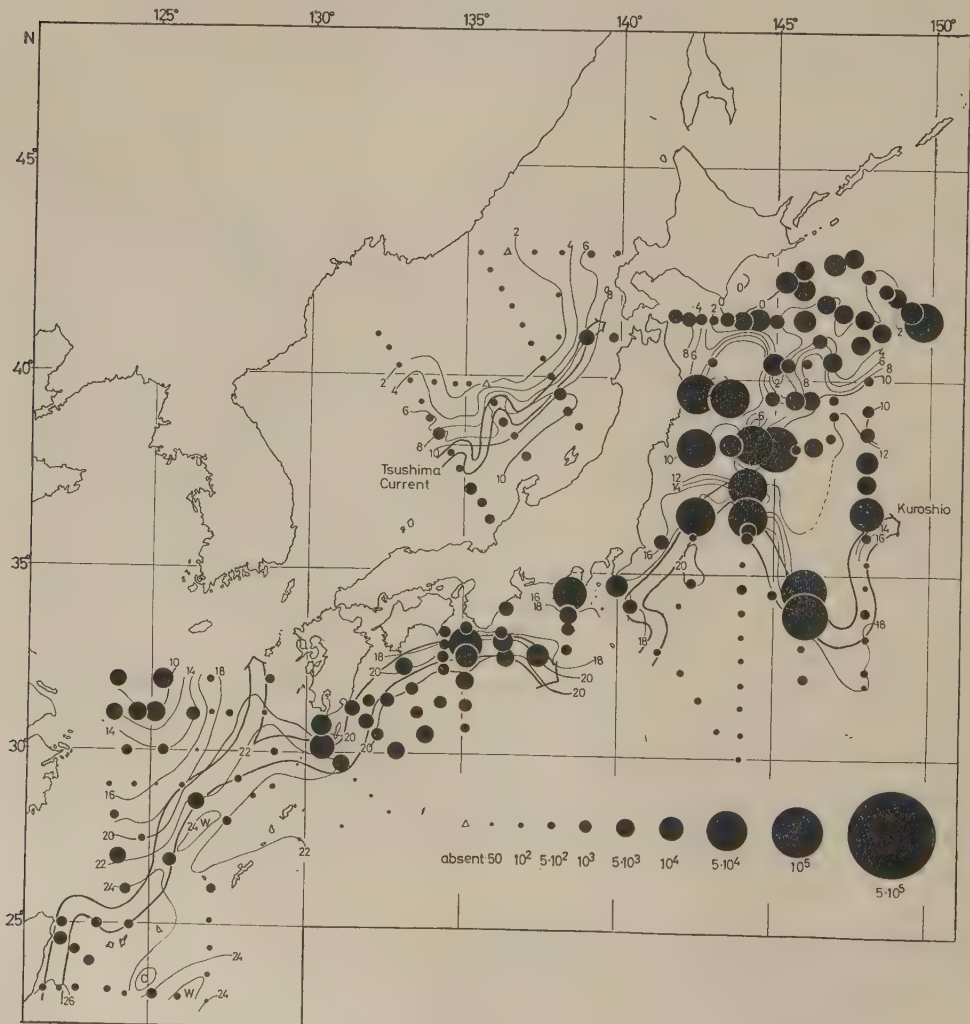


Fig. 1. Distribution of diatom standing crops (cells/l) and the temperature (°C) at the surface neighboring Japan from January to March 1966.

that the diatom standing crops in the Kuroshio Water both in the East China Sea and off the south coast of Japan are reduced to about one-fifth as compared with those in the winter of 1965, and on the contrary, off the east coast of Japan the densely populated areas which were restricted in the coastal regions in the winter of 1965, extend as far as long. 148°E.

In comparison with the winter of 1965, the Kuroshio flows more closely

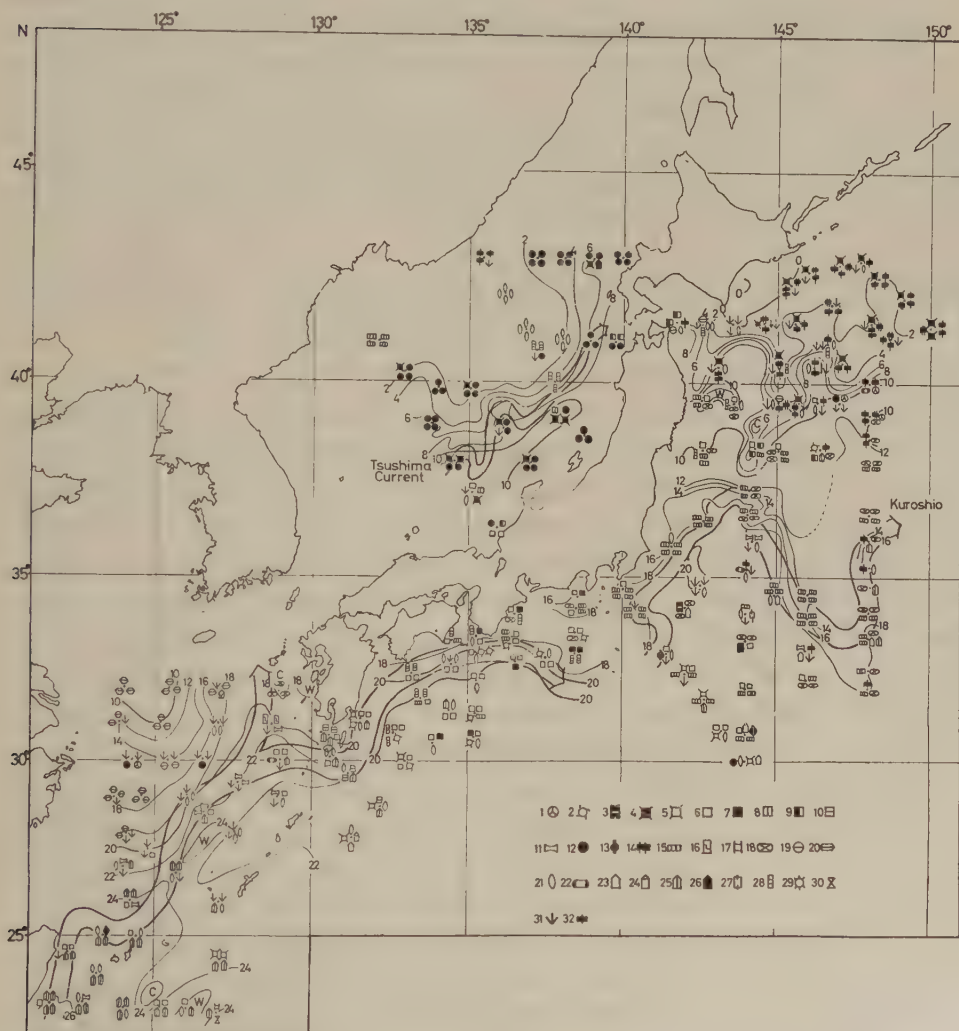


Fig. 2. Distribution of diatom communities and the temperature (°C) at the surface neighboring Japan from January to March 1966. Symbolized figures represent the

important diatom species. Each figure approximately corresponds to 20 per cent of total diatoms in occurrence. Specific names represented by the figures are given:

(1) *Actinopterychus undulatus*, (2) *Bacteriastrum comosum*, *B. delicatulum*, *B. elongatum*, *B. hyalinum*, *B. minus*, *B. varians*, (3) *Cerataulina bergoni*, (4) *Chaetoceros atlanticus*, *C. concavicornis*, *C. convolutus*, *C. densus*, (5) *Chaetoceros atlanticus* v. *neapolitana*, *C. atl.* v. *skeleton*, *C. denticulatus*, *C. rostratus*, *C. seychellarum*, (6) *Chaetoceros affinis*, *C. costatus*, *C. curvisetus*, *C. didymus*, *C. diversus*, *C. laciniosus*, *C. lorenzianus*, *C. messanensis*, *C. pseudocurvisetus*, (7) *Chaetoceros compressus*, *C. debilis*, *C. decipiens*, *C. radicans*, (8) *Chaetoceros decipiens*, (9) *Chaetoceros debilis*, (10) *Chaetoceros lorenzianus*, (11) *Climacodium frauenfeldianum*, (12) *Coscinodiscus asteromphalus*, *C. centralis*, *C. lineatus*, *C. excentricus*, *C. radiatus*, *C. stellaris*, *C. wailesii*, (13) *Dactyliosolen mediterraneus*, (14) *Denticula seminae*, (15) *Eucampia cornuta*, *E. zoodiacus*, (16) *Guinardia flaccida*, (17) *Hemiaulus hauckii*, (18) *Lauderia borealis*, (19) *Melosira borrieri*, (20) *Melosira sulcata*, (21) *Nitzschia closterium*, *N. delicatissima*, *N. longissima*, *N. seriata*, (22) *Pseudoenotia doliolus*, (23) *Rhizosolenia alata*, *R. bergonii*, *R. calcar avis*, *R. cylindrus*, *R. imbricata*, *R. robusta*, *R. setigera*, *R. stouterfothii*, *R. styliiformis*, (24) *Rhizosolenia alata*, (25) *Rhizosolenia stouterfothii*, (26) *Rhizosolenia hebetata* f. *semispina*, *R. hebetata* f. *hiemalis*, (27) *Schröderella delicatula*, (28) *Skeletonema costatum*, (29) *Stephanopyxis palmeriana*, (30) *Streptothecca indica*, (31) *Thalassionema nitzschioides*, (32) *Thalassiosira decipiens*, *T. gravis*, *T. hyalina*, *T. sp.*

along the coast of Japan in long. 131°E and far away from the coast in long. 138°E in the present survey. Therefore, the diatom standing crops in long. 131°E are much larger than those in the winter of 1965, but in long. 138°E they are not so different between the two years. Off the east coast of Japan the Kuroshio flows toward the northeast following the coast of Japan, reaching nearly to lat. 37°N in long. 144°E and turns the southeast toward lat. 33°N in long. 147°E. Then it turns again toward the north. Such a meandering of the Kuroshio is more remarkable than that in the winter of 1965, and so it is supposed that the occurrence of the dense populations of diatoms along the northern edge of the Kuroshio Water may be due to the course of the Kuroshio.

The diatom communities in the Kuroshio Water vary regionally: In the East China Sea they are composed of *Rhizosolenia stouterfothii*, *Climacodium frauenfeldianum* and warm water species of *Hyalochaete* group (*Chaetoceros affinis*, *Ch. curvisetus*, *Ch. laciniosus*, *Ch. messanensis*, *Ch. pseudocurvisetus*), and together with them *Nitzschia* spp. and *Thalassionema nitzschioides* are the second components of the communities. Off the south coast of Japan *Bacteriastrum* group (*B. comosum*, *B. delicatulum*, *B. elongatum*, *B. minus*, *B. varians*), warm water species of *Hyal.* group (*Ch. affinis*, *Ch. anastomosans*, *Ch. brevis*, *Ch. costatus*, *Ch. curvisetus*, *Ch. didymus*, *Ch. lauderi*, *Ch. lorenzianus*, *Ch.*

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messanensis, *Ch. pseudocurvisetus*) and *Nitz.* spp. are dominant in occurrence, and in addition, *Skeletonema costatum* and *Eucampia zoodiacus* are also found to be prevalent though to less extent. Off the east coast of Japan *Euc. zoodiacus* and *Lauderia borealis* become representative forms of the species compositions of diatoms. Among these species, *Hyal.* group is common between the East China Sea and the sea south of Japan, and *Euc. zoodiacus* between the seas south and east of Japan.

In comparison with the winter of 1965 the most characteristic properties of diatom communities in the present survey are as follows: In the East China Sea *Euc. zoodiacus* and *Laud. borealis* which were leading forms in last year are entirely absent in the present survey. On the contrary, off the south coast of Japan *Sk. costatum* joins in the diatom communities. Off the east coast of Japan the reductions of *Bact.* and *Hyal.* groups, *Rh. stolterfothii* and *Sk. costatum* are characteristic.

The occurrence of *Th'ma nitzschioides* in the Kuroshio Water in the East China Sea as well as *Sk. costatum* off the south coast of Japan indicates that the Kuroshio Water is much influenced by the neritic water. Moreover, the prevalent occurrences of neritic species as *Euc. zoodiacus* and *Laud. borealis* along the northern edge of the Kuroshio Water off the east coast of Japan show that the neritic water is transported by the Kuroshio far away from the coast.

(2) Waters south of the Kuroshio

Both in the East China Sea and in the sea east of Japan, the population density of diatoms is very small, being 10^2 to 10^3 cells. Off the south coast of Japan, however, it is considerably large, being 10^3 to $5 \cdot 10^3$ cells. Such distributional patterns of diatoms are fairly similar to those in the winter of 1965.

Although the diatom communities in the waters south of the Kuroshio are generally in accord with those in the Kuroshio Water, the occurrences of warm water species of *Phaeoceros* group including *Ch. atlanticus* v. *neapolitana*, *Ch. denticulatus*, *Ch. rostratus* and *Ch. seychellarum*, those which are all oceanic forms, are conspicuous.

(3) Waters over the continental shelf in the East China Sea

In the cold water area which is situated at the northwestern part of the East China Sea, the amounts of total diatoms are about $5 \cdot 10^3$ cells. The diatom communities here are characterized by the monotonous presence of *Melosira sulcata*. The planktological properties, such as the richness in diatom population as well as the prevalence of *Mel. sulcata* in occurrence are similar to those in

the winter of 1965.

In the winter of 1965 the large populations of diatoms, more than 10^4 cells, were found in the waters along the edge of the continental shelf, but in the present survey such a phenomenon is not observed. Therefore, the diatom standing crops in the waters west of the Kuroshio are small, less than $5 \cdot 10^2$ cells, except a few stations lying toward south, where the counts of diatoms are from $5 \cdot 10^2$ to 10^3 cells. The species compositions of diatoms here are composed of *Mel. sulcata*, *Th'ma nitzschioides* and *Nitz. spp.* Such a wide range of *Mel. sulcata* and the decrease of *Actinopterychus undulatus* in number are characteristic as compared with the winter of 1965. These facts indicate that the waters over the continental shelf are much influenced by the cold water from the Yellow Sea.

(4) Coastal regions

The coastal waters between the Kuroshio and the south coast of Japan are densely populated with diatoms, being 10^3 to $5 \cdot 10^4$ cells. Among them, in long. 138°E the total cell numbers of diatoms reach about $5 \cdot 10^4$ cells. The diatom communities vary regionally as the Kuroshio Water; the main components of the species compositions are *Rh. stolterfothii* and *Ch. lorenzianus* at the eastern end of the East China Sea, *Sk. costatum*, *Hyal. group*, *Euc. zoodiacus* and *Laud. borealis* off the south coast of Japan, and *Euc. zoodiacus* off the east coast of Japan.

(5) Japan Sea

In the Japan Sea, the population density of diatoms is generally small, being 10^2 to 10^3 cells. Especially, the oceanic water of low temperature below 6°C is poor in diatom, being about 10^2 cells as in the winter of 1965. The diatom communities are mainly composed of cold water species, such as *Coscinodiscus excentricus*, *Cos. lineatus*, *Cos. radiatus*, *Cos. wailesii*, *Nitz. seriata* and *Nitz. delicatissima*. Together with, *Ch. atlanticus*, *Ch. concavicornis*, *Ch. convolutus*, *Euc. zoodiacus* and *Thalassiosira subtilis* are also found though in small number.

In the Tsushima Current Water and the coastal waters between the Tsushima Current and the coast of Japan, the amounts of diatoms are larger than that in the oceanic waters, being $5 \cdot 10^2$ to 10^3 cells, but they are fairly smaller than those in the same season of 1965. The species compositions of diatoms are comprized of the nearly same species in the oceanic waters.

It seems that the amounts of total diatoms in the warm waters including the Tsushima Current Water and the waters between the Tsushima Current and

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the coast of Japan may be much influenced by those in the Kuroshio Water in the East China Sea; when the populations of diatoms in the East China Sea are small as in the present survey, diatoms are also poor in number in the Japan Sea, and on the contrary, when the population density of diatoms was large in the East China Sea as in the winter of 1965, the dense populations of diatoms were found in the Japan Sea. It is supposed from the fact of scantiness in diatom population as well as of the absence of the warm water species as *Euc. zoodiacus* and *Laud. borealis* that the inflow of the Kuroshio Water from the East China Sea is not yet strong.

(6) Oyashio and Transition Water

The Oyashio Water is densely populated with diatoms, being $5 \cdot 10^3$ to $5 \cdot 10^4$ cells. The diatom communities are composed of cold water species, such as *Ch. atlanticus*, *Ch. concavicornis*, *Ch. convolutus*, *Denticula seminae*, *Th'ra decipiens*, *Th'ra hyalina* and *Th'ra* spp., and neritic species as *Nitz. closterium*, *Nitz. delicatissima*, *Nitz. seriata* and *Th'ma nitzschoides*. In comparison with the winter of 1965 the species compositions of diatoms are similar each other, but the populations of diatoms are relatively large in the present survey.

In the Transition Water between the Kuroshio and the Oyashio Water the populations of diatoms are extremely large, being about $5 \cdot 10^4$ cells in the western part and 10^3 to $5 \cdot 10^3$ cells in the eastern part. The main components of the diatom communities also vary regionally; *Euc. zoodiacus* and *Laud. borealis* are widely distributed in the whole area, while *Ch. debilis*, *Sk. costatum* and *Nitz.* group are restricted in the western part and *Th'ra* group is found in the eastern part. As compared with the winter of 1965, the richness in diatom population in the western part and the wide range of *Euc. zoodiacus* are characteristic.

(2-2) Summer (July-October, 1966) (Figs. 3, 4)

(1) Kuroshio

In the Kuroshio Water the population density of diatoms is extremely small, less than 10^2 cells, except near the east coast of Taiwan, where the counts of diatoms are from 10^3 to 10^4 cells. In the summer of 1965 the amounts of diatoms were relatively large, being $5 \cdot 10^2$ to $5 \cdot 10^3$ cells. The diatom species occurred in the Kuroshio Water are as follows: *Act. undulatus*, *Asteromphalus flabellatus*, *Ast. heptactis*, *Bact.* group (*B. comosum*, *B. hyalina*, *B. minus*), *Hyal.* group (*Ch. affinis*, *Ch. laevis*, *Ch. lorenzianus*, *Ch. messanensis*, *Ch. paradoxus*, *Ch. pseudocurvisetus*, *Ch. tortissimus*), *Phaeo.* group (*Ch. atlanticus* v. *neapolitana*, *Ch. atl.*

v. skeleton, *Ch. coarctatus*, *Ch. dadayi*, *Ch. tetrastichon*), *Clim. biconcavum*, *Clim. frauenfeldianum*, *Cos. wailesii*, *Dactyliosolen mediterraneum*, *Euc. zodiacus*, *Hemiaulus hauckii*, *Leptocylindrus danicus*, *Nitz. group* (*N. closterium*, *N. longissima*, *N. seriata*), *Rhiz. group* (*R. alata*, *R. al.* f. *gracillima*, *R. calcar avis*, *R. castracanei*, *R. cylindrus*, *R. styliiformis*, *R. styl. v. longispina*, *R. stoltzerfothii*), *Sk. costatum*, *Stigmaphora rostrata*, and *Th'ma nitzschioides*. These

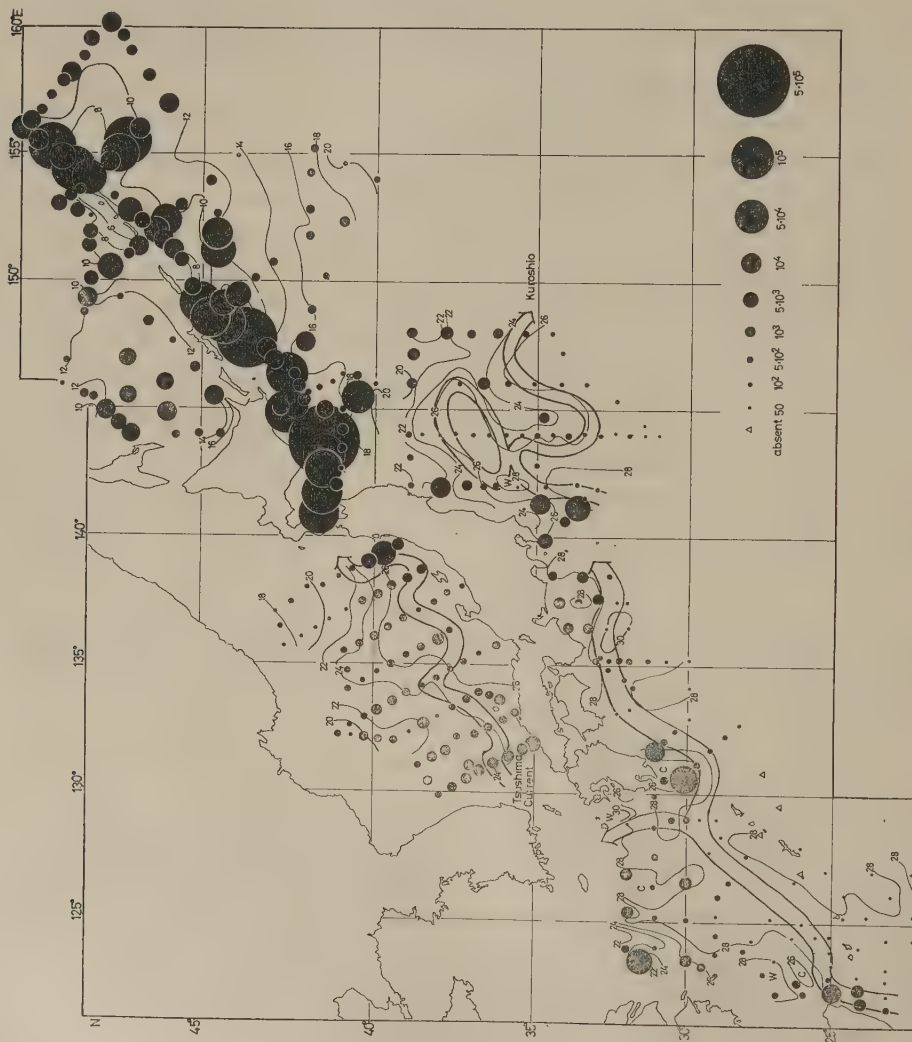


Fig. 3. Distribution of diatom standing crops (cell/L) and the temperature (°C) at the surface neighboring Japan from July to September 1966.

species also occurred in the Kuroshio Water during the summer of 1965.

The course of the Kuroshio is not so different from that in the summer of 1965 both in the East China Sea and off the south coast of Japan. However, off the east coast of Japan the Kuroshio flows far away from the coast of Japan in

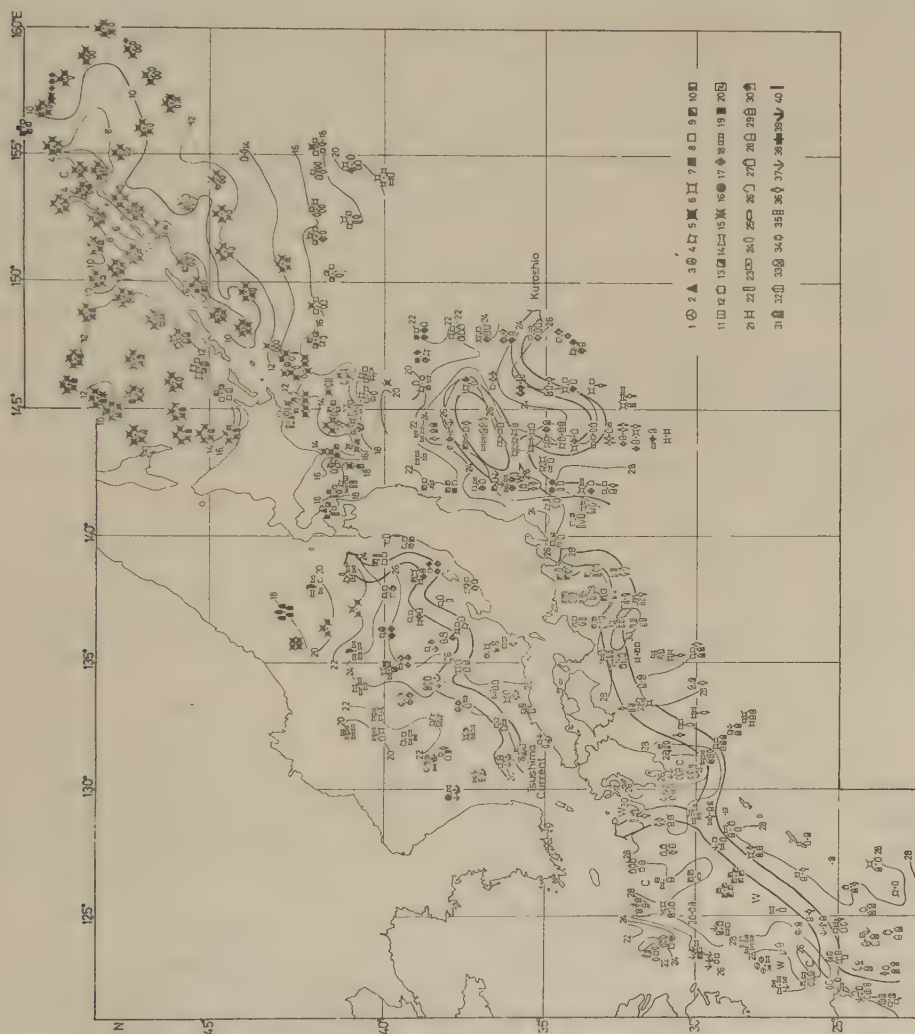


Fig. 4. Distribution of diatom communities and the temperature ($^{\circ}\text{C}$) at the surface neighboring Japan from July to September 1966. Symbolized figures represent the important diatom species. Each figure approximately corresponds to 20 per cent of total diatoms in occurrence. Specific names represented by the figures are given:

(1) *Actinopterychus undulatus*, (2) *Asterionella japonica*, (3) *Asteromphalus flabellatus*, *A. heptactis*, (4) *Bacteriastrum comosum*, *B. elongatum*, *B. delicatulum*, *B. hyalinum*, *B. minus*, *B. varians*, (5) *Chaetoceros atlanticus*, *C. concavicornis*, *C. convolutus*, *C. conv. f. trisetosa*, (6) *Chaetoceros atlanticus* v. *neapolitana*, *C. atl. v. skeleton*, *C. coarctatus*, *C. dadayi*, *C. pendulus*, *C. peruvianus*, *C. tetrastichon*, (7) *Chaetoceros debilis*, *C. compressus*, *C. constrictus*, *C. decipiens*, *C. radicans*, *C. subsecundus*, (8) *Chaetoceros affinis*, *C. curvisetus*, *C. decipiens*, *C. didymus*, *C. distans*, *C. diversus*, *C. laciniosus*, *C. laevis*, *C. lorenzianus*, *C. messanensis*, *C. paradoxus*, *C. pelagicus*, *C. tortissimus*, (9) *Chaetoceros compressus*, (10) *Chaetoceros debilis*, (11) *Chaetoceros decipiens*, (12) *Chaetoceros didymus* v. *anglica*, (13) *Chaetoceros radicans*, (14) *Climacodium biconcavum*, *C. frauenfeldianum*, (15) *Corethron hystrix*, (16) *Coscinodiscus lineatus*, *C. marginatus*, *C. oculus iridis*, *C. radiatus*, *C. walesii*, (17) *Dactyliosolen mediterraneus*, (18) *Eucampia cornuta*, (19) *Fragilaria oceanica*, (20) *Guinardia flaccida*, (21) *Hemiaulus hauckii*. (22) *Leptocylindrus danicus*, *L. minimus*, (23) *Navicula membranaceae*, (24) *Nitzschia closterium*, *N. longissima*, *N. seriata*, (25) *Pseudoeunotia dolichus*, (26) *Rhizosolenia alata*, *R. al. f. gracillima*, *R. bergonii*, *R. calcar avis*, *R. castracanei*, *R. cylindrus*, *R. delicatula*, *R. imbricata* v. *shrubsolii*, *R. stolterfothii*, *R. styliiformis*, *R. sty. v. latissima*, *R. sty. v. longispina*, (27) *Rhizosolenia alata*, *R. al. f. gracillima*, (28) *Rhizosolenia calcar avis*, (29) *Rhizosolenia cylindrus*, (30) *Rhizosolenia fragilissima*, (31) *Rhizosolenia hebetata* f. *semispina*, (32) *Rhizosolenia stolterfothii*, (33) *Rhizosolenia styliiformis*, *R. sty. longispina*, (34) *Schröderella delicatula*, (35) *Skeletonema costatum*, (36) *Stigmaphora rostrata*, (37) *Thalassionema nitzschioides*, (38) *Thalassiosira decipiens*, *T. sp.*, (39) *Thalassiothrix frauenfeldii*, (40) *Thalassiothrix longissima*.

long. 142°E. Besides the Kuroshio main current, there is a well-defined eddy centered in lat. 37°N and long. 144°E. Judging from the surface current, water temperature at various depths, and the planktological properties, this eddy may be formed by the cutoff of the Kuroshio.

(2) Waters south of the Kuroshio

In the waters south of the Kuroshio diatoms are poor in number as in the Kuroshio Water, being less than 10^2 cells, and moreover, the diatom species are similar to those occurred in the Kuroshio Water. The planktological properties such as the paucity of diatoms and the wide range of the warm water species of diatoms agree with those in the summer of 1965.

(3) Waters over the continental shelf in the East China Sea

In the cold water of temperature below 22°C which is situated at the north-western part of the East China Sea, the dense populations of diatoms are found, being $2 \cdot 10^4$ cells. The diatom communities here are mainly composed of purely neritic species such as *Nitz.* group and *Sk. costatum*. Excepting the cold water, the populations of diatoms over the continental shelf are from 10^2 to 10^3 cells. In the summer of 1965 the densely populated waters with diatoms were found between lat. 29°N and 30°N, but such distributional patterns of diatoms are not

observed in the present survey. The main components of the diatom communities are *Rh. alata*, *Rh. calcar avis*, *Rh. styliformis* and *Rh. styl. v. longispina* in the northern area, *Clim. biconcavum* and *Mel. sulcata* in the southern area, and *Ch. compressus*, *Ch. laevis* and *Th'ma nitzschioides* in the intermediate area between the two. The occurrence of *Mel. sulcata* which is usually the representative species of the cold water in winter is characteristic (JMA, 1962—1966, ASAOKA and MORIYASU, 1966).

In the waters over the continental shelf in the East China Sea, it seems that the distributional patterns of the populations of diatoms as well as the diatom communities do not show the similar features in the same seasons but vary annually.

(4) Coastal regions

The coastal waters between the south coast of Japan and the Kuroshio are populated with diatoms in relatively large number. Among them, both in long. 131°E and 141°E, the counts of diatoms reach about $2 \cdot 14^4$ cells. The main components of diatom communities are *Nitz.* group, *Lep. danicus*, *Hyal.* group, *Rhiz.* group and *Sk. costatum* in both regions. During the same season of last year, the dense populations of diatoms were also found in these regions, but the leading forms of the species composition were different from those in the present survey, i. e. *Ch. compressus* prevailed in occurrence in the former region and *Asterionella japonica* in the latter region.

There is an eddy between long. 136°E and 139°E, where the counts of diatoms are about 10^3 cells and the diatom communities are characterized by the predominant occurrence of *Ch. compressus*, together with *Nitz.* group, *Lep. danicus* and *Sk. costatum*.

It seems that the coastal waters along the south coast of Japan the diatom communities may be changed by the course of the Kuroshio.

(5) Japan Sea

The diatom standing crops in the southern half of the Japan Sea, lying south of lat. 41°N, are larger than those in the summer of 1965, but they are considerably small in the northern half. Especially, in the oceanic waters diatoms were poor in occurrence, less than 50 cells, during the summer of 1965. However, in the present survey the counts of diatoms in the waters south of lat. 41°N are from $5 \cdot 10^2$ to $5 \cdot 10^3$ cells. On the contrary, north of lat. 41°N the total cell numbers of diatoms are less than $5 \cdot 10^2$ cells, where they were from $5 \cdot 10^3$ to 10^4 cells in the summer of 1965.

The diatom communities in the southern half of the Japan Sea are composed of the warm water species such as *Bact. varians*, *Ch. danicus*, *Ch. peruvianus*, *Ch. tetrastichon*, *Ch. affinis*, *Ch. curvisetus*, *Ch. distans*, *Ch. lorenzianus*, *Clim. biconcavum*, *Dact. mediterraneum*, *Guin. flaccida*, *Hem. hauckii*, *Rh. al. f. gracillima*, *Rh. calcar avis*, *Rh. styliiformis*, *Rh. styl. f. latissima* and *Th'rix frauenfeldianum*, while in the northern half the cold water species, such as *Ch. concavicornis*, *Fragilaria* spp. and *Rh. hebetata f. semispina* are present together with the warm water species such as *Ch. peruvianus*, *Clim. biconcavum* and *Ch. affinis*.

Judging from the difference in diatom community as well as diatom population between the two regions, the northern half of the Japan Sea is shown to be of cold nature of water, where the surface water temperature is below 18°C, while the southern half reflects the warm nature of water which is transported by the branch of the Kuroshio from the East China Sea. Such a phenomenon was also found in the summer of 1965.

(6) Oyashio and Transition Water

The Oyashio is densely populated with diatoms which are present to the number of more than 10^5 cells. Especially, along the south coast of Hokkaido and the Kurile Islands, where the surface water temperature is from 4° to 8°C, the populations of diatoms are extremely large, reaching $5 \cdot 10^5$ cells at several stations, compared with other areas neighboring Japan. In the summer of 1965, though the dense populations of diatoms, being about 10^5 cells, were found at a few stations near Hokkaido, the amounts of diatoms in the Oyashio were about 10^4 cells on the average. Therefore, the occurrence of such a large population density of diatoms in the Oyashio in the present survey is characteristic. The diatom communities are mainly composed of cold oceanic species, such as *Ch. atlanticus*, *Ch. concavicornis*, *Ch. convolutus* and *Ch. conv. f. trisetosa*, and in addition to these species, *Ch. debilis*, *Nitz. closterium* and *Nitz. seriata* are also present in considerable number. Such diatom communities are similar to those in the winter except *Th'ra* group, so the Oyashio area is still shown to be of cold oceanic nature of water.

From the planktological properties, the Transition Water, lying between the Oyashio and the Kuroshio Waters, is divided into two parts; the coastal region west of long. 145°E and the oceanic region east of long. 145°E. In the coastal region, the populations of diatoms are considerably small, less than $5 \cdot 10^2$ cells, as in the Kuroshio Water, except a nearshore station, and the diatom communi-

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ties are composed of *Clim. biconcavum* and *Ch. compressus*. Whereas in the oceanic region the amounts of diatoms are more than 10^3 cells, and the main components of the diatom communities are *Ch. lorenzianus*, *Dact. mediterraneum*, *Rh. alata*, *Rh. al. f. gracillima* and *Rh. cylindrus*. Such distributional patterns of diatoms were found also in the summer of 1965.

(7) Okhotsk Sea

In the Okhotsk Sea the population density of diatoms is not so large compared with that in the waters near Hokkaido and along the Kurile Islands. The diatom standing crops are small, being about 10^3 cells, in the warm waters influenced by the Sōya Current, where the warm water species, such as *Bact. delicatulum*, *Ch. affinis*, *Ch. curvisetus*, *Rh. stolterfothii*, prevail. Excepting the above-mentioned areas, the amounts of diatoms are fairly large, being about 10^4 cells, and the diatom communities are characterized by the predominant occurrence of *Phaeo.* group, comprising of *Ch. atlanticus*, *Ch. concavicornis* and *Ch. convolutus*, together with *Rh. heb. f. semispina*. These species are all cold water forms which are usually occur in the Oyashio Water. Consequently, it is recognized from the view point of the planktological properties that the Oyashio Water is much influenced by the cold water originated from the Okhotsk Sea.

The standing crops of diatoms in the summer of 1966 are much larger than those in the summer of 1965. Moreover, the range of *Phaeo.* group in the present survey is far wide compared with that in the same season of last year, when *Phaeo.* group was restricted in the northeastern part of the investigated area.

3. Distribution of zooplankton biomass

(3-1) Winter (January-March, 1966) (Fig. 5)

(1) Kuroshio

Both in the East China Sea and in the sea east of Japan, the biomass in the Kuroshio Water is full of variety in distribution, especially conspicuous in the latter, where the extremely small biomass less than 25 mg per cubic meter of water is present, while the large one more than 100 mg is also present. On the contrary, in the sea south of Japan the biomass is maintained uniformly in small values in the range of 25 to 50 mg.

(2) Waters south of the Kuroshio

The biomass in the waters south of the Kuroshio is small on the whole;

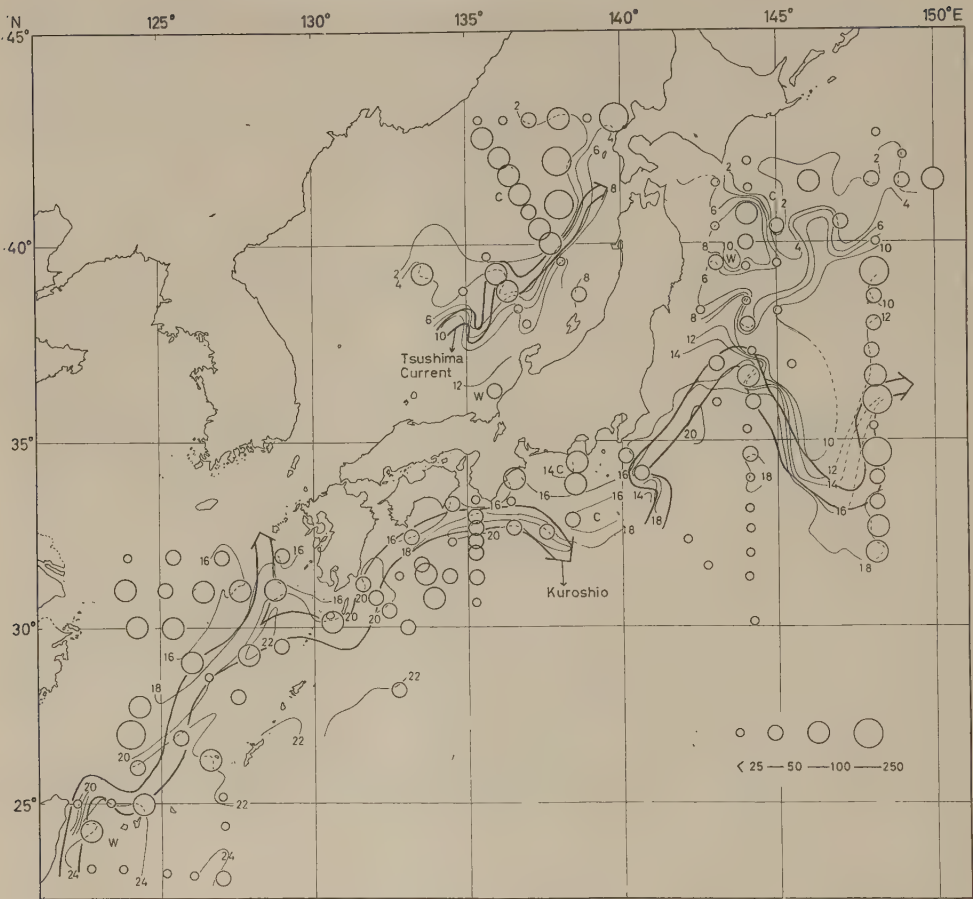


Fig. 5. Distribution of zooplankton biomass (mg/m^3 in wet weight) and the temperature at the 100 m depth neighboring Japan from January to March 1966.

both in the sea south of Japan and in the East China Sea it is in the range of 25 to 50 mg at two-thirds of stations, and both in the sea east of Japan and in the sea east of Taiwan it is less than 25 mg at most of stations.

(3) Waters over the continental shelf in the East China Sea

The waters over the continental shelf, except the cold water region located in the northwest of the East China Sea, is one of the areas with large biomass, being 50 to 100 mg . In the cold water region with a temperature below 10°C at the surface the biomass is small, less than 50 mg . In the narrow zone between the Kuroshio and the continental shelf the large biomass more than 100 mg is present.

(4) Coastal regions

In the coastal region between the Kuroshio and the southern coast of Japan, the biomass is changeful in distribution, varying from 5 to 100 mg, in comparison with that in the Kuroshio flowing along the southern edge of this region. In the coastal waters located in the northeast of the East China Sea, the biomass is small, being 25 to 50 mg.

(5) Japan Sea

In the cold water region north of the Tsushima Current, where a temperature at the depth of 100 m is below 6°C, the biomass is relatively large, being 50 to 250 mg at two-thirds of stations. In the Tsushima Current Water the biomass appears also to be large. In contrast with those two regions, in the region south of the Tsushima Current the biomass is small, less than 50 mg at most stations.

(6) Oyashio and Transition Water

In the Oyashio Water with a temperature below 6°C at the depth of 100 m, the biomass is relatively small, less than 50 mg at most stations. In the Transition Water between the Kuroshio and the Oyashio Water, the biomass is also small, where the biomass more than 50 mg is found at only two stations.

(3-2) *Summer (July-October, 1966) (Fig. 6)*

(1) Kuroshio

The biomass in the Kuroshio Water is variable in distribution, but any station more than 100 mg is not found. Thus the distinct difference of the biomass is not found between the winter and the summer.

(2) Waters south of the Kuroshio

The biomass is extremely small throughout the whole region, less than 25 mg at most of stations, therefore the distributional feature of the biomass is closely similar to that in the winter. However, in comparison with that in the summer of 1965 (KAWARADA *et al.*, *loc. cit.*) the marked decrease in biomass is found in the sea east of Japan; in 1965 the biomass was relatively large here, being almost 50 to 100 mg.

(3) Waters over the continental shelf in the East China Sea

In the waters over the continental shelf the increase in biomass is remarkable compared with the winter; the biomass is 100 to 500 mg at a half of stations. The large biomass more than 100 mg is also present in the narrow zone between the Kuroshio and the continental shelf.



Fig. 6. Distribution of zooplankton biomass (mg/m^3) in wet weight and the temperature at the 100 m depth neighboring Japan from July to October 1966.

(4) Coastal regions

In the winter the extremely small biomass, less than 25 mg, was found in the southern coast of Japan, but in the summer the biomass considerably increases, especially conspicuous in the region between long. 136°E and 139°E , where the biomass is 100 to 250 mg.

(4) Japan Sea

In the cold water region with a temperature below 6°C at the depth of 100 m, the biomass is relatively large, being 50 to 250 mg at most stations. In the Tsushima Current Water the large biomass more than 50 mg is also present,

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but in the region south of the Tsushima Current it is less than 50 mg. In general, the distributional patterns of the biomass in the Japan Sea resemble each other in both winter and summer.

(5) Oyashio and Transition Water

In the Oyashio Water with a temperature below 6°C at the depth of 100 m, the biomass becomes larger than that in the winter, being 100 to 500 mg at two-thirds of stations. Therefore, it is considered that in the Oyashio Water the reproduction of zooplankton is more vigorous in summer than in winter, taking the large biomass in the summer of 1965 into account.

In the Transition Water between the Kuroshio and the Oyashio Water, the biomass appears to be small, less than 50 mg, except the large warm eddy centered in lat. 37°N, long. 144°E. In that eddy it is somewhat large, being 25 to 100 mg, and this range of biomass is similar to that of the Kuroshio Water.

(6) Okhotsk Sea

The biomass in the Okhotsk Sea seems to be large, being more than 100 mg at half of stations.

4. Distribution of chaetognaths

(4-1) Winter (January-March, 1966) (Figs. 7, 8)

(1) Kuroshio

The chaetognath population in the Kuroshio Water is variable in distribution; both in the East China Sea and in the sea east of Japan the population is in the range of 1.0 to 10.0 inds. per cubic meter of water and in the sea south of Japan in the range of 2.5 to 25.0 inds.

The Kuroshio Water is rich in species and the main constituents of the chaetognath composition vary geographically. In the East China Sea many warm water forms, such as *Sagitta bedoti*, *S. enflata*, *S. ferox*, *S. hexaptera*, *S. lyra*, *S. minima*, *S. neglecta*, *S. pacifica*, *S. pseudoserratodentata*, *S. regularis*, *Pterosagitta draco*, *Krohnitta pacifica* and *K. subtilis* are frequently present. Among them *S. enflata* is important as the main constituent of the composition, and either *S. minima* or *S. bedoti* which is well known as the tropico-neritic form is added as the second one at a few stations.

In the sea south of Japan main forms of the chaetognath composition are *S. enflata*, *S. minima* and *S. lyra*. It is noticed here that *S. bedoti* disappears

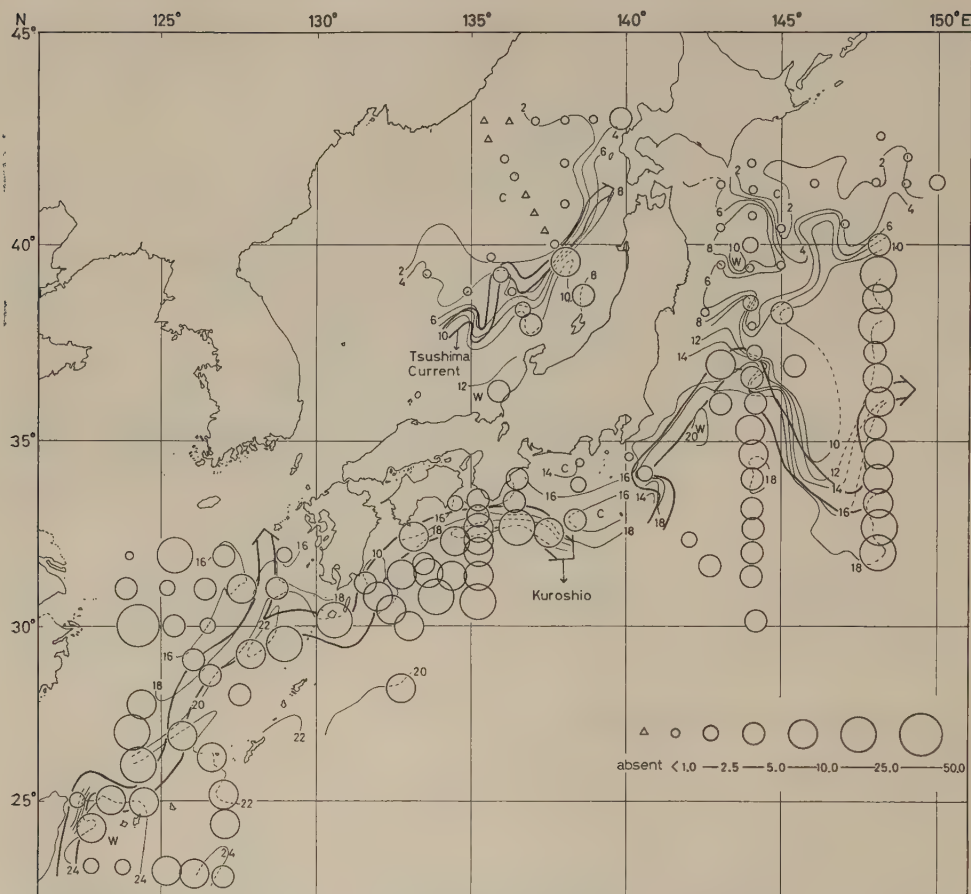


Fig. 7. Distribution of chaetognath population (inds./m³) and the temperature at the 100 m depth neighboring Japan from January to March 1966.

and *S. nage* which is the commonest of chaetognaths around Japan as the neritic form occurs at a few stations in low proportion of total chaetognaths.

In the sea east of Japan the main constituent is replaced by *S. minima*, and sometimes *S. enflata* or *S. nage* contributes to the composition as the second element. *K. pacifica* which is reported as the indicator species of the oceanic water of the equatorial region (BIERI, 1959) is not found here.

(2) Waters south of the Kuroshio

The East China Sea, the sea south of Japan and the sea east of Taiwan are densely populated with chaetognaths, being 5.0 to 10.0 inds. at most of stations, and rich in species as in the Kuroshio Water. The main constituents of the

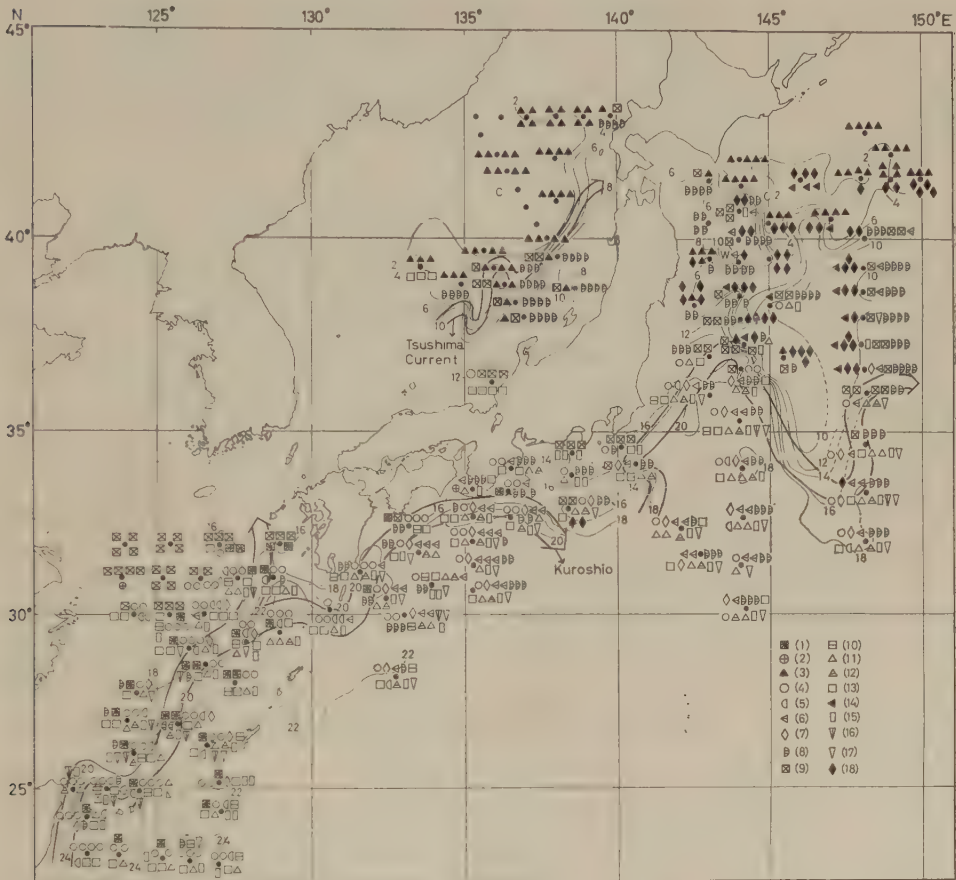


Fig. 8. Distribution of chaetognath communities and the temperature ($^{\circ}\text{C}$) at the 100 m depth neighboring Japan from January to March 1966. Symbolized figures represent the important chaetognath species. Number of symbols in a station indicates the percentage of animals; below 10%, 10-25%, 25-50% and above 50% of total chaetognaths. Specific names represented by the figures are given:

- (1) *Sagitta bedoti*, (2) *S. crassa* f. *naikaiensis*, (3) *S. elegans*, (4) *S. enflata*, (5) *S. ferox* and *S. robusta*, (6) *S. lyra*, (7) *S. hexaptera*, (8) *S. minima*, (9) *S. nagae*, (10) *S. neglecta*, (11) *S. pacifica*, (12) *S. pseudoserratodentata*, (13) *S. regularis*, (14) *S. scrippsae*, (15) *Pterosagitta draco*, (16) *Krohnitta pacifica*, (17) *K. subtilis*, (18) *Eukrohnitta hamata*.

chaetognath composition also vary geographically; in the former two regions *S. enflata* is the main one and sometimes *S. regularis* and *P. draco* are also important together with it, and on the contrary, in the latter region the main constituents are replaced by *S. minima* and *S. lyra*.

In the sea east of Japan chaetognaths decrease in number, being 1.0 to 5.0 inds. at two-thirds of stations. The main components are *S. minima* and *S. lyra* as in the sea south of Japan. It is noticed here that *Eukrohnia hamata* which is a deep water form in the sea south of the Kuroshio, is present at the station located in lat. 33°20'N, long. 148°10'E.

(3) Waters over the continental shelf in the East China Sea

In the cold water region located in the northwest of the East China Sea, chaetognaths are changeful in number, being from 1.0 to 25.0 inds., and this region is characterized by the monotonous occurrence of *S. nagae*.

Chaetognaths also vary in number in other regions including the narrow zone between the continental shelf and the Kuroshio, but the chaetognath composition is rich in species and dominated by both *S. enflata* and *S. regularis*. *S. bedoti* is widely distributed in those regions, though its proportional abundance of the total chaetognaths is low.

(4) Coastal regions

In general, coastal waters between the Kuroshio and the southern coast of Japan are sparsely populated with chaetognaths. In the region close to the coast between long. 138°E and 141°E, *S. nagae* is the dominant form of the chaetognath composition, but in the other region *S. minima* is important as the main constituent and one species among the three species of *S. enflata*, *S. regularis* and *P. draco* is important as the second constituent.

In this waters as well as in the sea east of Japan, a remarkable phenomenon is observed, that is, *E. hamata* is collected in the cold water region centered in lat. 33°N, long. 134°E, where a temperature at the depth of 100 m is below 16°C. This animal has never been collected in the sea south of Japan by shallow towing from the depth of 100 m to the sea surface, according to the plankton data obtained by the Japan Meteorological Agency (1961-1966).

In the coastal waters situated in the northeastern part of the East China Sea, the population is small, being 1.0 to 2.5 inds., and the composition is formed by two species of *S. nagae* and *S. bedoti*.

(5) Japan Sea

The cold water region north of the Tsushima Current with a temperature below 6°C at the depth of 100 m is characterized by the sparse population of chaetognaths, less than 1.0 inds., and the monotonous occurrence of *S. elegans*, except the southern edge where the admixture of warm water forms, such as *S. regularis* and *S. minima* and neritic form, such as *S. nagae*, takes place.

The Tsushima Current Water and the warm region south of it are populous compared with the cold water region, more than 1.0 inds. at most stations and 6.7 inds. in the maximum. In the warmest region more than 12°C at the depth of 100 m, the chaetognath composition consists of three species of *S. regularis*, *S. enflata* and *S. nagae*, but in the other region it is dominated by *S. minima*.

(6) Oyashio and Transition Water

The Oyashio Water with a temperature below 6°C at the depth of 100 m is the most sparsely populated with chaetognaths in the Pacific, as the counts of chaetognaths are less than 1.0 inds. at most stations. Three species of *S. elegans*, *S. scrippsae* and *E. hamata* are present; among them *S. elegans* is commonest.

In the Transition Water between the Kuroshio and the Oyashio Water, the population density of chaetognaths is larger in the eastern half than in the western half; less than 2.5 inds. in the former and 2.5 to 10.0 inds. in the latter. *S. minima*, *S. nagae*, *S. scrippsae* and *E. hamata* are present frequently; among them *S. minima*, *E. hamata* and *S. nagae* are main constituents of the chaetognath composition. The typical warm water forms decrease in species number here; *S. enflata*, *S. pacifica*, *P. draco* and *K. subtilis* remain in places, while the typical cold water form, *S. elegans* also decreases in occurrence.

(4-2) Summer (July-October, 1966) (Figs. 9, 10)

(1) Kuroshio

The chaetognath population in the Kuroshio Water somewhat increases compared with that in the winter, being in the range of 5.0 to 25.0 inds. per cubic meter of water.

In the East China Sea *S. enflata* is the most important species of the chaetognath composition, and one species among three species of *S. regularis*, *S. neglecta* and *K. pacifica* is important as the second component. Both in the seas south and east of Japan *S. minima* becomes main component together with *S. enflata*. In addition to these species *S. regularis* and *P. draco* are also added as the second components in the sea south of Japan.

Moreover, a characteristic distribution of both *S. bedoti* and *K. pacifica* is found; the two species are frequently present in the Kuroshio Water, whereas they are seldom in the Kuroshio flowing in the sea south of Japan and absent in the Kuroshio flowing in the sea east of Japan in winter. Thus the Kuroshio Water in the seas south and east of Japan as well as in the East China Sea in summer reflects the nature of the equatorial water influenced by the tropico-neritic water.

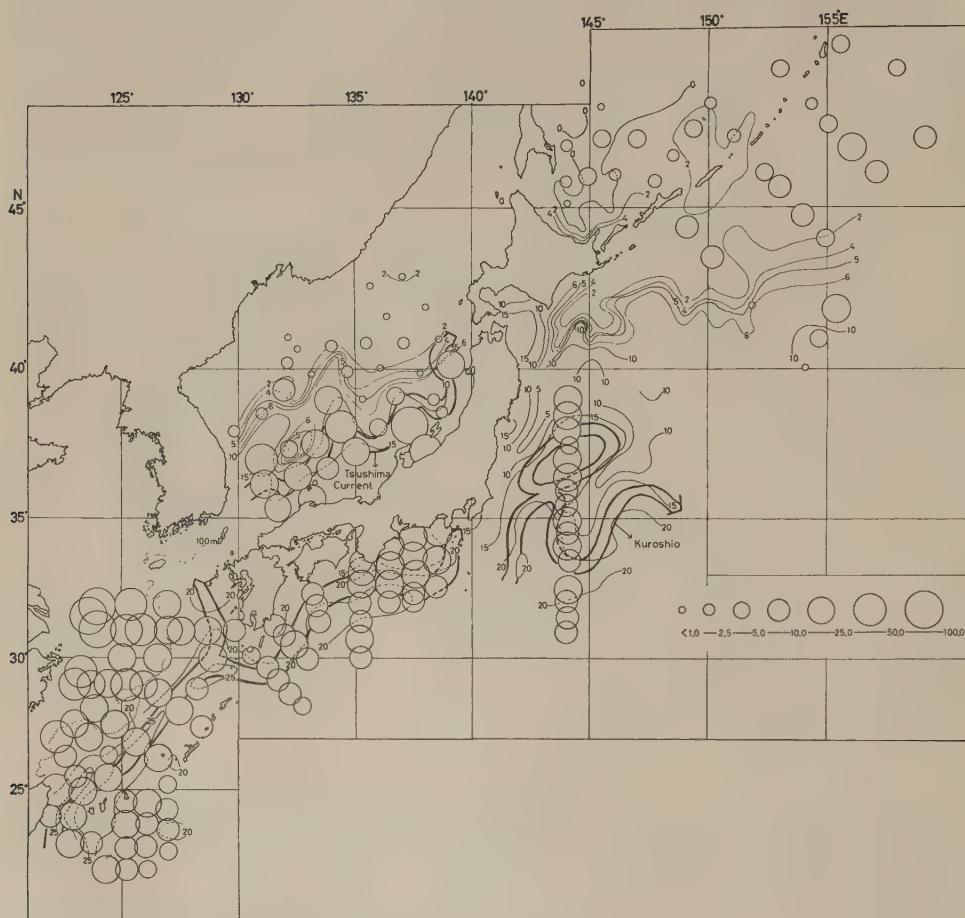


Fig. 9. Distribution of chaetognath population (inds./m³) and the temperature at the 100 m depth neighboring Japan from July to October 1966.

(2) Waters south of the Kuroshio

In the waters south of the Kuroshio the population increases compared with that in the winter, being 5.0 to 25.0 inds. at most stations. Many warm water species, such as *S. enflata*, *S. ferox*, *S. lyra*, *S. hexaptera*, *S. minima*, *S. neglecta*, *S. pacifica*, *S. pseudoserratodentata*, *S. regularis*, *P. draco*, *K. pacifica* and *K. subtilis* are present. However, the main constituents of the chaetognath composition are different from each region.

Both in the East China Sea and in the sea east of Taiwan, *S. enflata* is the important species as the main constituent of the composition, and *S. regularis*,



Fig. 10. Distribution of chaetognath communities and the temperature ($^{\circ}\text{C}$) at the 100 m depth neighboring Japan from July to October 1966. Symbolized figures represent the important chaetognath species. Number of symbols in a station indicates the percentage of animals; below 10%, 10-25%, 25-50% and above 50% of total chaetognaths. Specific names represented by the figures are given:

(1) *Sagitta bedoti*, (2) *S. crassa* f. *naikaiensis*, (3) *S. elegans*, (4) *S. enflata*, (5) *S. ferox* and *S. robusta*, (6) *S. lyra*, (7) *S. hexaptera*, (8) *S. minima*, (9) *S. nagae*, (10) *S. neglecta*, (11) *S. pacifica*, (12) *S. pseudoserratodentata*, (13) *S. regularis*, (14) *S. scrippsae*, (15) *Pterosagitta draco*, (16) *Krohnitta pacifica*, (17) *K. subtilis*, (18) *Eukrohnna hamata*.

S. neglecta and *S. pacifica* are also added as the important ones at a few stations. Both in the seas south and east of Japan, *S. minima* contributes to the chaetognath composition as the main constituent, and *S. enflata*, *S. hexaptera*, *S. lyra*,

S. regularis, *S. pseudoserratodentata*, *P. draco*, *K. pacifica* and *K. subtilis* become important in place. It is noticed here that *S. bedoti* which is frequently present in the East China Sea and in the sea east of Taiwan is rare in the sea south of Japan and absent in the sea east of Japan.

(3) Waters over the continental shelf in the East China Sea

In the waters over the continental shelf the chaetognath population remarkably increases compared with that in the winter, especially in the cold water region where a temperature at the surface is below 24°C, being in the range of 50.0 to 100.0 inds. The cold water region becomes rich not only in number, but also in species. Among six species of *S. enflata*, *S. nagae*, *S. pacifica*, *S. ferox*, *P. draco* and *K. pacifica*, *S. enflata* is main component of the composition, and *S. nagae* is added as the second component.

In other regions over the continental shelf the species number increases, but *S. nagae* is not found south of 30°N parallel.

(4) Coastal regions

The increase of the chaetognath population is conspicuous in the coastal waters between long. 136°E and 140°E, being 10.0 to 25.0 inds. *S. enflata*, *S. minima*, *S. regularis* and *S. nagae* are main constituents of the chaetognath composition.

Both in the coastal waters located in the northeastern part of the East China Sea and in the coastal waters located west of long. 136°E in the sea south of Japan, chaetognath population is not so large, being 2.5 to 10.0 inds., and the dominant form is *S. enflata*.

(5) Japan Sea

In the cold water region with a temperature below 6°C at the depth of 100 m, the chaetognath population increases to some extent compared with that in the winter, but it is not so large, less than 2.5 inds. This region is divided into two parts by the species composition of chaetognaths; in the eastern half the composition consists of only one cold species of *S. elegans*, while in the western half consists of *S. elegans*, *S. nagae*, and *S. crassa* f. *naikaiensis* which is a typical inlet form.

In the Tsushima Current Water and the warm water region south of it, the chaetognath population increases remarkably, more than 10.0 inds. at most stations, but the chaetognath fauna is poor in species even in the summer compared with that in the Kuroshio Water or in the sea south of the Kuroshio. Among seven species of *S. enflata*, *S. minima*, *S. neglecta*, *S. nagae*, *S. regularis*,

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S. crassa f. *naikaiensis* and *K. pacifica*, *S. minima* is the most important species as the main constituent of the chaetognath composition, except one station close to the coast of Japan, where *S. enflata* and *S. regularis* are present dominantly.

In the region between the Tsushima Current and the cold water region, the chaetognath population is changeful in distribution, being 2.5 to 50.0 inds., and an admixture of various forms of chaetognaths takes place.

In the summer of 1966, the most interesting phenomenon on the distribution of chaetognaths is that *S. crassa* f. *naikaiensis* is distributed widely in the central part of the Japan Sea, whereas it is absent in the winter of 1966 and seldom present in the summer of 1965. *S. crassa* f. *naikaiensis* is not found along the coast of Japan as well as near the Kuroshio which reached the northernmost part of the East China Sea. According to PARK's study (1967), however, this animal is commonly distributed along the coast of Korea including the west channel of Tsushima Straits in the summer of 1966. Thus it is reasonably considered that the spread of *S. crassa* f. *naikaiensis* to the offing is not only due to the Tsushima Current, but also due to the Tōsen (East Korean) Warm Current which is a branch of Tsushima Current, and flows northwards along the east coast of Korea and then turns the direction to the east in about lat. 38°N.

(6) Oyashio and Transition Water

In the Oyashio Water with a temperature below 6°C at the depth of 100 m, the chaetognath population fairly increases compared with that in the winter, being more than 5.0 inds. at most stations, and the chaetognath composition consists of two cold water forms, such as *S. elegans* and *E. hamata*, except the southern edge of this water where *S. minima*, *S. crassa* f. *naikaiensis*, *S. nagae* and *S. scrippsae* are present together with those two species. Accordingly, it will be said that the Oyashio Water is more productive in summer than in winter, as to chaetognaths.

The increase in the chaetognath population also takes place in the Transition Water between the Kuroshio and the Oyashio Water. As for chaetognaths, the distinct difference between in the winter and in the summer is found not only on the population, but also on the composition; in the summer *E. hamata* disappears here, whereas in the winter it composed of main part of the composition together with *S. minima*.

In the large warm eddy centered in lat. 37°N, long. 144°E, both the population and the composition are closely similar to those in the Kuroshio Water, which indicates that it is not so long after the eddy has been cut off

from the Kuroshio.

(7) Okhotsk Sea

Although the population density is lower than that in the Oyashio Water, less than 5.0 inds., yet the faunas of the Oyashio Water and the Okhotsk Sea are just the same; two species of *S. elegans* and *E. hamata* are more or less present.

However, *E. hamata* is entirely absent in the Japan Sea, therefore the cold water of the Japan Sea is different from the cold water of the Pacific in nature.

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